Estimation of source model of the 1931 NISHI-SAITAMA earthquake using long-period ground motion at Hongo in Kanto basin

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The 1931 Nishi-Saitama earthquake occurred in the northwestern part of Saitama prefecture on September 21, 1931 with a magnitude of 6.9. This is one of the most destructive shallow crustal earthquakes in the Kanto district in the last 100 years. Heavy building damage was experienced in the epicentral area during the quake. It is important from the viewpoint of disaster mitigation to know the source model of the earthquake for considering ground shaking during future events. Abe (1974) estimated the focal depth according to observed P-wave travel time in distant station and suggested shallow focal depth. However, the focal depth has not been precisely understood.
In this study, we tried to estimate a source model of the 1931 Nishi-Saitama earthquake by comparing a long-period seismogram observed in Hongo, Tokyo, which is the only seismogram recorded completely in the Tokyo Metropolitan area with synthetic seismograms simulated by a 3D finite differential method considering recent detailed model of the Kanto basin. It is clarified that the main part of the observed long-period seismogram is composed of surface waves affected by the three-dimensional effect of the sedimentary layers in the Kanto basin. We also found good agreement between the calculated and observed seismograms, when the depth of the source fault is set to be in a range of 20-30 km with a rupture propagating from the bottom edge of the center of the fault.

Keywords: The 1931 Nishi-Saitama earthquake, long-period seismogram, focal depth

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Source inversion using EGF for the 2008 Iwate-Miyagi earthquake based on precisely relocated aftershock distribution

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During the 2008 Iwate-Miyagi Nairiku earthquake, the peak ground accelerations at several stations exceeded 1G. The faulting mechanism of this event was considered to be the west-dipping reverse fault from the CMT solution, initially estimated aftershock distribution and the location of surface deformation. On the other hand another source model that the conjugate faults are ruptured simultaneously has been proposed recently based on the precisely relocated aftershock distribution (Yoshida, 2013) and the geodetic data detected by the GPS and the In-SAR (Abe et al., 2013). The source modeling using strong motion data was also carried out assuming conjugate fault plane, and significant slips are estimated on both the fault planes (Hikima and Koketsu, 2013). In this study the conjugate fault planes model and west-dipping plane model are prepared based on the aftershock locations by Yoshida (2013) and the waveform inversion using the empirical Green's function is applied.

The initial conjugate fault model for the inversion analysis in this study consists of three planes. For the west-dipping fault I assume two planes with different strike and dip angles according to the latest aftershock distribution and the trace of surface deformation. Furthermore the east-dipping conjugate fault plane is added. Observed records from two aftershocks of Mj 4.2 and 4.0 occurring near the northern and southern fault planes are adopted for the empirical Green's functions. Velocity motions of two horizontal components for 20 near-source stations are used for the source inversion in the frequency range from 0.1 to 1 Hz. The difference of the radiation patterns between the main shock and EGFs are corrected following Boore and Boatwright (1984).

The obtained source model from the conjugate fault indicates large slips mainly in the southern part from the hypocenter on the west-dipping northern fault plane and secondary large slips on the east-dipping fault. The slip distribution of the source projected on the horizontal plane shows that the slips on the conjugate faults are complementary. The maximum slip reaches 5.3 m. While the source model with west-dipping fault plane implies the main slips are estimated on the almost same area and the peak value is 6.1 m. For both cases though the asperity on the west-dipping fault is located beneath the trace of observed surface deformations, it lies in rather deeper position. It is considered to be consistent with the fact that the surface fault ruptures are not observed clearly.

Keywords: The 2008 Iwate-Miyagi earthquake, source inversion, empirical Green's function

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Dynamic source parameters of the 2008 Iwate-Miyagi inland earthquake inferred from kinematic source model

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The spatial and temporal distributions of the stress on the fault planes of the 2008 Iwate-Miyagi Inland earthquake (M_0=2.4×10^{19} Nm, M_w6.9) is calculated from kinematic inversion result using a three-dimensional finite difference method for solving the elastodynamic equations. This event is dip-slip with surface rupture. We analyze the relations between stress and slip for all grid positions on the fault, and use these relations to infer the friction law for the rupture dynamics. Then, the dynamic source parameters were also determined. The distributions of the dynamic parameters on the fault are very heterogeneous. Average of dynamic stress drop on the asperity is ~13 MPa. Average fracture energy over the entire fault is estimated ~6 MJ/m^2, which coincides with the seismic moment relationship by Tinti et al. (2005). The fracture energy is proportional to the final slip. In general, the stress drop and fracture energy are correlated with the slip distribution. Rupture time on each subfault is determined based on peak stress time. The rupture propagation was gradually accelerated in the asperity, and was delayed along the surface. For the surface rupture earthquake, we estimate small or negative stress drop and small fracture energy, where large slip is estimated along the surface.
Acknowledgements: This study was based on the 2015 research project ‘Improvement for uncertainty of strong ground motion prediction’ by the Nuclear Regulation Authority (NRA), Japan.

Keywords: The 2008 Iwate-Miyagi inland earthquake, Dynamic source parameter, Kinematic source model

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Dynamic source parameters of the 2013 Tochigi-ken hokubu earthquake inferred from kinematic source model

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Revealing detailed source rupture processes for past large earthquakes is an essential study to make the advanced characterized source model for reliable strong motion prediction. Though the concept of characterized source model in a “recipe” is based on the result from kinematic source model, the physics of source rupture process in nature is represented by dynamic model, which is described as an evolution of shear stress with the frictional property on the fault. For understanding a more physically accurate model to make the ground motion, the study on strong motion simulation with dynamic source model has been developed in decades. In this study, we estimate the spatio-temporal stress change and dynamic source parameters on and off the asperity from kinematic source model of the 2013 Tochigi-ken hokubu, Japan, earthquake (M_w 5.8) as a part of advanced characterized source modeling toward the prediction of strong motion.
The spatio-temporal stress change on the fault is calculated from kinematic source model using a three-dimensional finite difference method (FDM) for solving the elastodynamic equations (e.g., Ide and Takeo, J. Geophys. Res., 102, 27379-27391, 1997). We employ the heterogeneous source model inverted from strong motion records in 0.1-1.0 Hz by Somei et al. (JpGU, SSS23-P19, 2014) as the kinematic source model input to FDM calculation. Each subfault size is divided into 250 x250 m from 1.0 x1.0 km, which is original size of inversion model, by bi-linear interpolating. We use the Staggered grid in FDM calculation. From the estimated stress change and slip amount, we extract the dynamic source parameters assuming the frictional constitutive law for each subfault.
The obtained dynamic source parameters are static and dynamic stress drops, effective stress, strength excess, critical slip-weakening distance (D_c), and fracture energy (G_c). We tried to evaluate the average value for each dynamic source parameters on and off the asperity, and to compare them for each other. The asperity area is defined as a rectangular area by characterizing the final slip on kinematic source model. The principal findings in this study are as follows: 1) The asperities have 2 times larger D_c than the off asperity area. 2) D_c's on and off the asperities are about 50 % of the final slip amount. 3) Static and dynamic stress drops on the asperity are 3-5 times larger than those on the off asperity area. 4) Average static and dynamic stress drops, and effective stress on the asperity are 6.0, 6.7, and 7.7 MPa, respectively. 5) Strength excess tends to be large on the edge of the asperity.

Acknowledgements: This study was based on the 2015 research project ‘Improvement for uncertainty of strong ground motion prediction’ by the Nuclear Regulation Authority (NRA), Japan.

Keywords: The 2013 Tochigi-ken hokubu earthquake, Dynamic source parameter, Kinematic source model

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Slip velocity funtion for strong motion evaluation based on the hybrid method

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1. Introduction

Broad-band strong motion in general has been estimated by the hybrid method, long-period motions by a numerical method and short-period motions by a semi-empirical method. Ground motions from the long-period calculation and those from the short-period calculation are combined using matching filter about 1Hz. The synthesized waveforms by the hybrid method fit the observed records well in the previous researches (e.g. Kamae et al., 1998).

Slip velocity functions used above are different in the target frequency ranges. For example, smoothed ramp function, Nakamura and Miyatake’s function (2000) and so on are used for the long period calculation. On the other hand, in case of the short-period calculation the slip time function is not directly defined but given as a convolution of the slip time function of small event with a correction function defined by Irikura (1986).

Therefore, the slip velocity function in intermediate period range from 0.5 to 1.0 s is expressed as the summation of the theoretical slip time function given in the long-period range and the empirical one in the short-period range.

However, there is a possibility that the combined spectra have some sag in the intermediate period range,

In this study, we discuss ground motion characteristics between the long-period waveform and short-period waveform in the intermediate period range during 2008 Iwate Miyagi Nairiku earthquake. First, strong motions generation area (SMGA) during this earthquake was estimated by the empirical Green’s function method (Irikura, 1986). Second, theoretical long-period waveform was calculated by discrete wavenumber method (Bouchon, 1981) based on High Rate Area (HRA) characterized source model. We examine whether the both spectra of the synthesized waveforms are smoothly connected.

2. Estimation of Strong Motion Generation Area (SMGA)

SMGA source model during 2008 Iwate Miyagi Nairiku earthquake was already estimated by Kurahashi and Irikura (2013, 2014). We re-estimated the SMGA source model, because Yoshida et al. (2015) re-estimated the characterized source model which was constructed from slip distribution by the waveform inversion. Yoshida et al. (2015) proposed HRA characterized source model from peak moment rate distribution. Yoshida et al. (2015) thought that short-period strong motion is generated from HRA because short-period strong motion relates slip velocity function. Therefore, we re-estimated the SMGA source model by the empirical Green’s function method (Irikura, 1986) referring to the HRA characterize source model. As a result, the synthesized waveform based on the HRA characterized source model agrees with the observed one.

Next, the long-period waveform was calculated by the discrete wavenumber method (Bouchon, 1981). Parameters of the slip time function were determined to comparison between the observed and synthesized waveform. We discuss how to select the slip velocity time function to smoothly connect between the long-period and short-period calculations.

Keywords: slip velocity function, the hybrid method, 2008 Iwate Miyagi nairiku earthquake

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Study on spectral decay characteristics in high frequency range using parameter κ- For crustal earthquakes -

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Spectral decay parameters κand f_E due to crustal earthquakes are estimated in this study. In high frequency range spectra of S-wave accelerations are generally characterized by a trend of exponential decay, $e^{-\pi f \kappa}$ ($f>f_E$), while they are modeled with f_{max} filter in Japanese applications. The κ's of the three large earthquakes are estimated in the range 0.0142 and 0.0277 and f_E's are estimated in the range 2Hz and 5Hz for the mainshocks of the 2003 Miyagi-ken Hokubu earthquake, the 2005 Fukuoka-Ken Seiho-oki earthquake, and the 2008 Iwate Miyagi Nairiku earthquake. The relationship between κand the power coefficient of f_{max} filter, *s*, and the relationship between f_E and f_{max} are evaluated from the results. Moreover, hypocentral distance dependency of κis confirmed as demonstrated by previous studies.

Keywords: Spectral decay characteristics, Kappa, fmax filter, Crustal earthquakes

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Stochastic Green’s Function Method Incorporated Empirical Site Effects in Time Domain

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Site effects make a great impact on ground motions on Earth’s surface, in particular at places underlain by soft soils. For make an accurate estimation of ground motion, site effects need to be quantitatively evaluated in time domain, including phase information (hereinafter called the site effects as "non-stationary site effects"), although so far only amplitude spectra of the site effects are taken into account. Akazawa et al. (2009) developed a method for estimating the non-stationary site effects using the wavelet analysis and many seismic records. The method gives average amplitude property (envelope) depending on frequency and coherent phase of seismic records. Akazawa et al. (2009) showed the applicability of the method by demonstrating for the observed seismic records for small events.
We simulate observed seismic records for large events (e.g. the 2011 Tohoku Earthquake) by incorporating the non-stationary site effects, which was proposed by Akazawa et al. (2009), with the stochastic Green’s function method. Bedrock ground motions from a small event are stochastically simulated with the omega-squared model and an envelope time function depending on source size and propagation path. Bedrock ground motions from a large event are evaluated taking fault model into account in the same procedure as the empirical Green’s function. Surface ground motion from the large event is calculated with a convolution of the bedrock motion with the non-stationary site effects. This method applied to some large events whose source models are known. The simulated results agree well with the obtained seismic records.

Keywords: Site Effects, Time Domain, Stochastic Green’s Function Method, Strong Ground Motion Method

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Broadband ground motion prediction considering variabilities of source parameters and comparison with observed records

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The strong motion prediction “recipe” (Earthquake Research Committee, 2009) has proposed the characterized source model whose source parameters are determined by the scaling laws that extract average characteristics of the source parameters of past earthquakes. Consequently, the predicted ground motion of the National Seismic Hazard Maps using the characterized source models with a limited number of locations of the asperities and hypocenters may be at average level, which is insufficient for prediction of unknown earthquake ground motion. In order to overcome this problem, two approaches may be important. One is to comprehend the variabilities of the source parameters by analyzing the ground motion records of past earthquakes. The other is to introduce probabilistic source models and perform large amount of ground motion computation.
In this study, we attempt to perform “ground motion prediction” of past earthquakes by using source models that take into account the variabilities of source parameters. The 2000 western Tottori earthquake is chosen as our first target earthquake. Aleatory variabilities of selected source parameters are assumed to have normal distributions whose means and standard deviations are estimated from the recipe, and the source models are constructed by sampling the source parameters by the Latin Hypercube Sampling (LHS), following the method by Yamada et al. (2007, 2011). Variabilities of five parameters are considered; the (1) short-period level (ratio to $M_0^{1/3}$), (2) slip within the asperities (ratio to the average slip), (3) rupture velocity (ratio to the shear-wave velocity of the source region), (4) asperity locations, and (5) hypocenter location.
As a preliminary analysis, we constructed source models in which the short-period level, asperity slip, and rupture velocity have either the mean or mean+SD values with fixed locations of asperities and hypocenter. Broadband ground motion was computed by a hybrid method of 3D FDM and the stochastic Green’s function method. By comparing the simulation results with each other and with observation via an evaluation method using the 5% damped pseudo acceleration response spectra (PSA) at 40 stations with hypocentral distance of 1 –180 km (Goulet et al. 2015), we found that The basic case (all parameters have the mean values) over- and underestimated the PSA at long- (> 1 s) and short- (< 1 s) periods, respectively. The mean+SD short-period level amplified the PSAs at all stations at periods 1 s and shorter. The influence of the mean+SD rupture velocity model largely varied among the stations.
We will conduct ground motion simulations for ~100 source models in which all the five parameters are sampled by LHS. We will evaluate the variability of the predicted ground motions and compare them with the observed records. It is important to perform these analyses for various other past earthquakes in order to compare the variabilities of the predicted ground motions with those of the observed ground motions.

Keywords: ground motion prediction, source model, variability

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Introduction of rupture directivity effect into the pseudo point-source model

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The pseudo point-source model (Nozu, 2012) is a simple source model for strong ground motion simulation. This simple source model has been applied to some earthquakes and shown good agreement with observations as well as the characterized source model.
In the pseudo point-source model, subevents which generate strong ground motions are assumed on the fault plane and a source spectrum which follows the omega-square model is given to each subevent. This means the spacio-temporal distribution of the slip within the subevent is not explicitly considered in the pseudo point-source model. Thus, parameters concerning rupture propagation such as the size of the subevent are not necessary. However, by giving a corner frequency properly the size of the subevents is implicitly taken into account.
A problem of the pseudo point-source model is that the rupture directivity effect is not considered. This is because we assume a source spectrum for each subevent without considering rupture propagation. As a result, the same source spectrum is used for forward and backward stations and underestimations can happen at stations where forward directivity is observed. In a previous study (Nagasaka et al., 2015) in which this model was applied to the 2005 Central Chiba earthquake (M_w5.9), the results were generally good, however, underestimation was found in the west of the epicenter and this could be attributed to the fact that the current pseudo point-source model does not consider rupture directivity effect. To avoid such underestimation is important when this model is to be used for earthquake-resistant design.
In this study, in order to introduce rupture directivity effect into the pseudo point-source model, we investigated the applicability of a corner frequency model representing rupture directivity effect. The target is the 2005 Central Chiba earthquake (M_w5.9). First, we searched for the optimal corner frequencies at each target station as the error between synthetic and observed Fourier spectra becomes minimum. The result was that the optimal corner frequency was about 1.0Hz in the west of the epicenter where underestimation was found in the previous study, in which the corner frequency of 0.75Hz was used for all the target stations. Therefore, this result indicates that forward directivity could have affected the stations to the west of the epicenter. The optimal corner frequencies were smaller at surrounding stations; this also implies that introducing rupture directivity effect can improve the pseudo point-source model.
Then, we assumed a unilateral rupture along a line source to model the corner frequency. Under this condition, the corner frequency becomes a function of the angle between the direction of rupture propagation and wave propagation to a target station (φ). New source parameters we need are the length of the rupture (L), the rupture velocity (V_r) and the direction of the rupture propagation. Then the corner frequency (f_c) can be represented as $f_c=(V_r/\pi L)(1-V_r/V_s \cdot \cos\varphi)$. This means that the corner frequency varies depending on the apparent duration of the rupture; the corner frequency is higher in the forward region and lower in the backward region with respect to the rupture propagation. We plan to search for the parameters that minimize the error between the observed and synthetic Fourier spectra. Then, this result will be compared with the result of the previous study (f_c=0.75Hz). In addition, the rupture propagation indicated by the optimal parameters will be compared with the rupture process of the earthquake estimated from waveform inversion.

Keywords: strong ground motion simulation, pseudo point-source model, rupture directivity effect, corner frequency

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High Frequency Ground Motion Simulation of an Un-happened ShanChiao Fault in Northern Taiwan from an ETF-Based Site Correction Method for Stochastic Simulation

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Strong motion generation area (SMGA) was mentioned as an important source parameter for high frequency strong motion simulation (Kurahashi and Irikura, 2011) that was identified as different asperity distribution from traditional source inversion results. Meanwhile, high frequency strong motion simulation is very important in application of engineering seismology. Site correction method from Empirical Transfer Function (ETF, Wen et al., 2013) for stochastic finite fault simulation was applied in Northwestern Taiwan for 1999 ChiChi Taiwan earthquake as high frequency simulation. Except the traditional inverted asperity model was used, random asperity distribution ones were test from Huang et al. (2014). In this study, different construction method of random asperity models followed Japan’s Recipe (Irikura et al., 2004; NIED, 2009) are constructed for the same event first to check near fault response for randomly SMGAs. ShanChiao fault is the most important fault system in northern Taiwan owing to it could probably generate earthquake directly hit the Capital urban area. Finally, this study will try to identify possible ground shaking level for Shanchiao Fault system. The simulation results could help to preliminary plan of disaster prevention issue or building design problems in the future.

Keywords: Stochastic Simulation, Empirical Transfer Function, SMGA, ShanChiao Fault

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Simulation of long-period ground motions for the 2011 Tohoku earthquake (Mw9.0) using large-scale parallel computing

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In the 2011 off the Pacific coast of Tohoku Earthquake (Mw9.0), long-period earthquake ground motions were recorded all over Japan including KiK-net Konohana in Osaka. It is important to clarify the reproducibility and the propagation characteristics of long-period ground motions to improve the S-wave velocity model of deep sedimentary layers and predict ground motions of the large earthquake occur in Nankai troughs. To simulate the earthquake ground motion for all over Japan, we developed a parallel computing program using 3D finite difference method based on domain decomposition. We simulated the earthquake ground motions of the March 11 main shock using the developed program, and examined the reproducibility of earthquake ground motions at periods from 2 to 10s in the Metropolitan area.

For effective parallel calculations of earthquake ground motions using 3D finite difference method, we deployed 3 computers equipped with 2 CPUs made by Intel (E5-2690v3, 12 cores) and memory cards of 192Gbyte in each node. We connected 3 nodes using the InfiniBand of 40Gbps transmission speed and constructed the calculation environment that enabled 72 parallel computing with inter-node communication using MPI. The parallel calculation was based on the 3D domain decomposition to utilize a large number of cores which were equipped in each node effectively, and used MPI in intra-node communication as well. We checked the parallel efficiency by simple examples. Scalability was approximately 15 times in case of 32 processes. When we used another PC cluster (16 nodes, 2 CPUs, 8 cores), scalability was approximately 60 times in case of 64 processes. Overall execution time was shortened approximately as expected.

We simulated long-period earthquake ground motions of the March 11 main shock using pseudo point-source model (Nozu, 2012) for the purpose of examining the applicability of point-source at periods from 2 to 10s. Source time functions were triangle type and the number of time window was 1. Dip angle was 90 degrees for all point-sources. Rise times were set based on the corner frequencies of Nozu (2012). We used S-wave velocity model of deep sedimentary layers of Headquarters for Earthquake Research Promotion (2012). The calculational domain was East-West 300km, North-South 600km, and vertical 100km. We digitized the model with grid of 0.2km for horizontal and 0.1km to 1.0km for vertical. Total number of grids was approximately 1,600 million, and duration time was set to 300s with the time interval of 0.005s. We finished calculation of 60001 steps in less than two days. When we compared observed and simulated earthquake ground motions at periods from 2 to 10s, shapes of the spectra were well reproduced although amplitudes at periods from 6 to 10s were underestimated in the metropolitan area likely due to the point-source modeling. Surface waves (T=6-10s) generated around south of Ibaraki Prefecture propagated toward the metropolitan area were almost reproduced except for amplitude. Continuously, we are going to adjust the source model of the March 11 main shock, and investigate the propagation characteristics of long-period ground motions. In addition, we will implement the developed program in the Earth Simulator.

Keywords: parallel computing, finite difference method, the 2011 off the Pacific coast of Tohoku Earthquake, long-period ground motion

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Benchmark Test for Strong Motion Simulation in The Tokyo Metropolitan Area.

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We conducted a benchmark tests for strong motion simulation methods .
we simulated the long-period ground motions in the Kanto sedimentary basin using the 2005 northwestern Chiba earthquake (M6.0) , and using the supposed Tokyo metropolitan earthquake in STEP8.

Keywords: Strong ground motion prediction, Benchmark test

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A New Attenuation Relationship for Velocity Response Spectra at the surface

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We integrated the attenuation relationships proposed by Matsu’ura et al.(2011) to be able to predict the velocity response spectrum for an arbitrary source at an arbitrary site in wide range of distance and period. We divided data into three groups of source types as follows: inter-plate, intra-plate, and very shallow earthquakes. In order to determine parameters at once, we expand each parameter by cubic B-splines, as Yabuki and Matsu’ura(1992) did, and transform the problem to be solved in a linear inversion. We also introduce the upper limit of the plate depth at a site to be considered, such as 250km for PAC slab, by comparing AICs for various limit depth and various types of formulae.

Sv_{ij} is the velocity spectrum at the *i*-th site of hypocentral distance $DELTA_{ij}$, where the depth of subducting slab is dep_i, due to the *j*-th earthquake of Mw_j with the residual of e_{ij}. For inter-, and intra-plate earthquakes, the relation is the form of Eq. (1), while for very shallow earthquakes, Eq. (2) is the form. Here, t is the period.

$\log Sv_{ij}(Mw_j, DELTA_{ij}, dep_i, t)= Mw_j\, A_w(t) +A_c(t)-Beta(t)\log(DELTA_{ij})-d(t)dep_i+e_{ij}(t)$ Eq.(1)

$\log Sv_{ij}(Mw_j, DELTA_{ij}, t)= Mw_j\, A_w(t)+A_c(t)-b(t)DELTA_{ij}-Beta(t)\log(DELTA_{ij})+e_{ij}(t)$ Eq.(2)

In Eq. (1), the term with the coefficient *b(t),* which is always contained in conventional engineering formulae of the attenuation relationship for response spectra, is omitted. We found: 1) the term with *b(t)* in Eq. (2) works to represent the plateau shape of spectra in very small *DELTA*, especially in short period. 2) The coefficient *Beta(t),* which we introduced, works well alone to fit data of inter- and intra-plate earthquakes without *b(t)*, since data with very small *DELTA* are rare for those types of earthquakes in Japan. 3) Even in Eq. (2), *b(t)* is nearly zero for periods over about 2sec. 4) The coefficient *d(t)* in Eq. (1), which is usually believed to represent the effect of High-Q and High-V subducting slab, is even effective to represent the effects from large scale of geological structure differences in Japanese crust, such as rather low Q features of western part of the northeastern Japan, and the attenuation discrepancy between the east and west of the Hida mountains.

The site response $e_{ij}(t)$ *is almost independent of the source types,* Mw_j, *and* $DELTA_{ij}$, *i.e. nearly equal to* $e_i(t)$. It was empirically confirmed that $e_i(t)$ can be replaced by H/V spectral ratio obtained from the observed micro-tremors. Eqs. (1) and (2) can be used to calculate velocity spectra at any site for any expected sources without knowing AVS30 or geotechnical classification of that site.

This study was done by the trust from Ministry of Education, Culture, Sports, Science and Technology.

Keywords: Attenuation relationships of Velocity Response Spectra, Upper limit of the effective plate depth at a site, Selection by AIC, linear inversion method with cubic B-spline expansion

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Validation of Attenuation Relationships for Velocity Response Spectra, Comparing with Observed Records

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An attenuation relationship for velocity response spectra has been proposed for wide range of period and distance by Noda *et al.* (2016), which is referred to as N2016 model hereafter. The optimum functional form of attenuation relationship was determined from observed records by using AIC. In this study, in order to validate the obtained relationship, we compare its result with observed one or with other previous studies.
For the comparison, we select two inter-plate earthquakes (the 2003 Tokachi-oki and the 2011 Tohoku-oki), three intra-plate earthquakes (the 2003 Miyagi-oki, the 2004 off the Kii peninsula, and the 2011 Miyagi-oki), and three crustal earthquakes (the 2000 Western Tottori, the 2005 west off Fukuoka, and the 2008 Iwate-Miyagi Nairiku). These events have magnitude lager than Mw6.6, and we can use a lot of observed records from K-NET and KiK-net. As previous studies, we select attenuation relationships obtained by Uchiyama and Midorikawa (2006), Satoh (2008, 2010), and Morikawa and Fujiwara (2013). Since these previous models are constructed for acceleration response spectra, we transform predicted amplitudes calculated from the previous models into pseudo-velocity response spectra. We calculate velocity or pseudo-velocity response spectra at free surface by multiplication of site amplification factors revealed by each researcher, and then compare them with observed velocity response spectra, for period ranging from 0.1 to 5 sec, within applicable range of each model.
The spectral amplitudes predicted by N2016 model agree well with the observation over a wide range of distances, up to farther than 200km. Furthermore, the dispersion of residuals between the predicted and observed amplitudes is very small over a wide range of periods, from 0.1 to 5sec. On the other hand, though the previous models explain well short-period components of the observed response spectra for distances shorter than about 150 km, the dispersion of residuals between observed and their predicted amplitudes increases with distance. The good agreement between observation and N2016 model is mainly for two reasons: (1) effectivity of attenuation terms proportional to depth of subducting slab, (2) regarding coefficients of attenuation terms proportional to logarithm of distance as unknown quantities for each period. The latter suggests that we cannot assume a priori that the coefficients are 1.0 in the Japan Islands. We can attribute the small dispersion of N2016 model to effectivity of site amplification terms, which is obtained from residuals for each period, at each station.
This study was made by the trust from Ministry of Education, Culture, Sports, Science and Technology.
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Keywords: attenuation relationship, velocity response spectra

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Probabilistic Seismic Hazard in Low Seismicity Region: Kalimantan, Indonesia

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The island of Kalimantan lies upon the southeastern margin of the greater Eurasian plate. The features that affected Kalimantan came from its great tectonic activity during Late Paleozoic-Pliocene.The absence of present-day major earthquakes makes the island is considered as a relatively stable block. In the past decades, seismic hazard analysis in Kalimantan is not prioritized due to its low seismicity. However, two moderate yet destructive earthquakes hit the island in 2015: the 6.5 Mw Sabah (Northern part of Kalimantan, Malaysia) earthquake on June 5, and the 6.1 Mw Tarakan (Eastern part of Kalimantan, Indonesia) earthquake on December 21. It seems that the eastern and northern parts of the island are subject to potential hazard from small to medium sized earthquakes. Those recent earthquakes show that Kalimantan is not sterile from destructive earthquakes. Hence, we must remain alert to the possibility of such an earthquake disaster, as it had happened last year and 95 years ago. In addition, more than 18 million people living in this island should be considered.

In order to reduce earthquake disaster, the Kalimantan seismic hazard map was created using probabilistic approach called PSHA. The uncertainties of size, location and time of earthquake sources and GMPE were taken into account in calculation of acceleration. Seismic hazard analyses involve the quantitative estimation of ground-shaking intensity that was obtained by converting the acceleration on 0.3 second RSA (Response Spectral Acceleration) having 10% probability of exceedance in 50 years (500 years return period). Based on ground-shaking intensity, the hazard level was divided into four classes: they are very low (MMI < V), low (V ≤MMI ≤VII), moderate (VII < MMI ≤VIII), and high (MMI > VIII) respectively.Important to note, this classification is primarily intended to non-engineered building, a common building in Indonesia.

The hazard level in Kalimantan is mainly controlled by diffuse zones of deformation (background seismicity) while Palu Koro and/or North Sulawesi subduction affected eastern tip of Mangkalihat Peninsula. The inclusion of site amplification is another important aspect that included in the hazard map, since it can change the hazard level significantly.

Keywords: PSHA, Kalimantan , Low Seismicity Region, Seismic Hazard Map

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The Impact of Westward Extension of Flores Back-Arc and The Inclusion of an Active Crustal Fault in Southeastern Bali to Bali Seismic Hazard Map (Preliminary Results)

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Recent study utilising Global Positioning System (GPS) measurements of surface deformation conducted in western area of Lesser Sunda Islands, show the westward extension of Flores Back-Arc for 300 km onshore into East Java. Another recent study, utilising geology, geophysics and geodetic methods reveal indication of an active crustal fault in southeastern Bali which pass Denpasar, the capital city of Bali Province and the most dense city in its province. The Implications of these findings are the increasing hazard and risk levels in Northern and Southeastern parts of Bali. Seismic hazard analyses (deterministic and probabilistic) using OpenQuake show increasing hazard levels compared to the previous seismic hazard map of Bali. The direct impacts are the number of people and buildings affected by the inclusion of these seismic sources increase significantly. The preliminary results show the need for a careful evaluation of the infrastructures and contingency plan within areas which affected by these seismic sources in order to ensure the safety of the people and to reduce loss of infrastructures.

Keywords: Back-Arc, Active crustal Fault, Seismic Hazard Analyses, OpenQuake

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A proposal for creating a maximum seismic intensity map of past damaging earthquakes

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The Headquarters for Earthquake Research Promotion of Japan has created and published national seismic hazard maps, in principle, every year after the 1995 Hyogo-ken Nanbu earthquake. This hazard map has two problems. One is that probabilities cannot be easily understood by citizens. The other is that the method includes large uncertainties and has not been inadequately tested yet. The results, therefore, are less reliable.
We propose creating a maximum seismic intensity distribution of past damaging earthquakes. This maps may be easily understood by citizens, the method has small uncertainties and the result is more reliable. The distribution is two-dimensional and is enable citizens to know the maximum seismic intensity at their own backyard. The previous seismic intensity maps for historical earthquakes show the intensity only at the observation point, and the citizens cannot know the intensity at their own backyard.
Citizens in areas of large intensities may have a conscious to earthquakes. However, we should inform citizens in areas of small intensities that the area may not be safe in the future. It is preferable that this maps is supplementally used.
This study develops a map in Kumamoto prefecture for damaging earthquakes after the Meiji era as a prototype. We applied attenuation relationships for seismic intensity (Morikawa et al., 2010). We use fault planes if faults is estimated or hypocenters if the fault plane is not estimated to calculate distances in the equation. We also use the elevation data of the National Land Numerical Information download service to calculate distances. We use data of average shear-wave velocity in the upper 30 m distributed by the Japan Seismic Hazard Information Station. We estimate seismic intensity at each block of 250 m mesh for each earthquake and plot the maximum intensity at each block.
Seismic intensity of 4 (in JMA scale) are distributed in the most of Kumamoto prefecture due to the 1946 Nankai (M8.0) and 1968 Hyuganada (M7.5) earthquakes. High intensity (5 lower-6 higher) are distributed around Kumamoto city due to the 1889 Kumamoto earthquake (M6.3).

Keywords: seismic intensity, disaster prevention

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Amplification characteristics in Kanto district estimated from waveforms of the 2015 Ogasawara Deep earthquake with Mw8.0

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A deep large earthquake with Mw8.0 took place beneath the Ogasawara islands on May 30, 2015. This earthquake caused a large shaking in Kanto district in Japan with the JMA intensity of 4 to 5 major, which provides an opportunity to investigate the amplification characteristics in the region.
We analyzed waveforms of 56 KiK-net sites in Kanto district and investigated the spectral ratio of the observed waveforms at stations on the surface and on the bedrock in the borehole at each site. We first picked arrival times of P and S waves and cut the waveforms from -10.00 to 30.95 s after the arrivals. We then calculated spectra of the waveforms and obtained the spectral ratios of P and S waves. We calculated average values of spectral ratios in the frequency band from 0.1 to 1 Hz (Fig. 1a) and attributed them to amplification factors at each KiK-net station.
We first investigated the relationship between the observed amplification factors and distances of surface and borehole seismometers. The relationship showed a good proportionality with a correlation coefficient of 0.744, indicating that the factors have a strong correlation with the thickness of the sediments the same as results of previous studies. We then calculated the normalized amplification factors (NA factors) for every 100 m of the distance between surface and bedrock stations to remove the effect associated with different thickness of sediment at each site (Fig. 1b). The NA factors were around 1 for sites at mountain regions as expected. In the Kanto plain, only sites around the Tone river had high NA factors.
Acknowledgements: We used KiK-net waveform data.

Keywords: Spectral ratio, KiK-net, Kanto district

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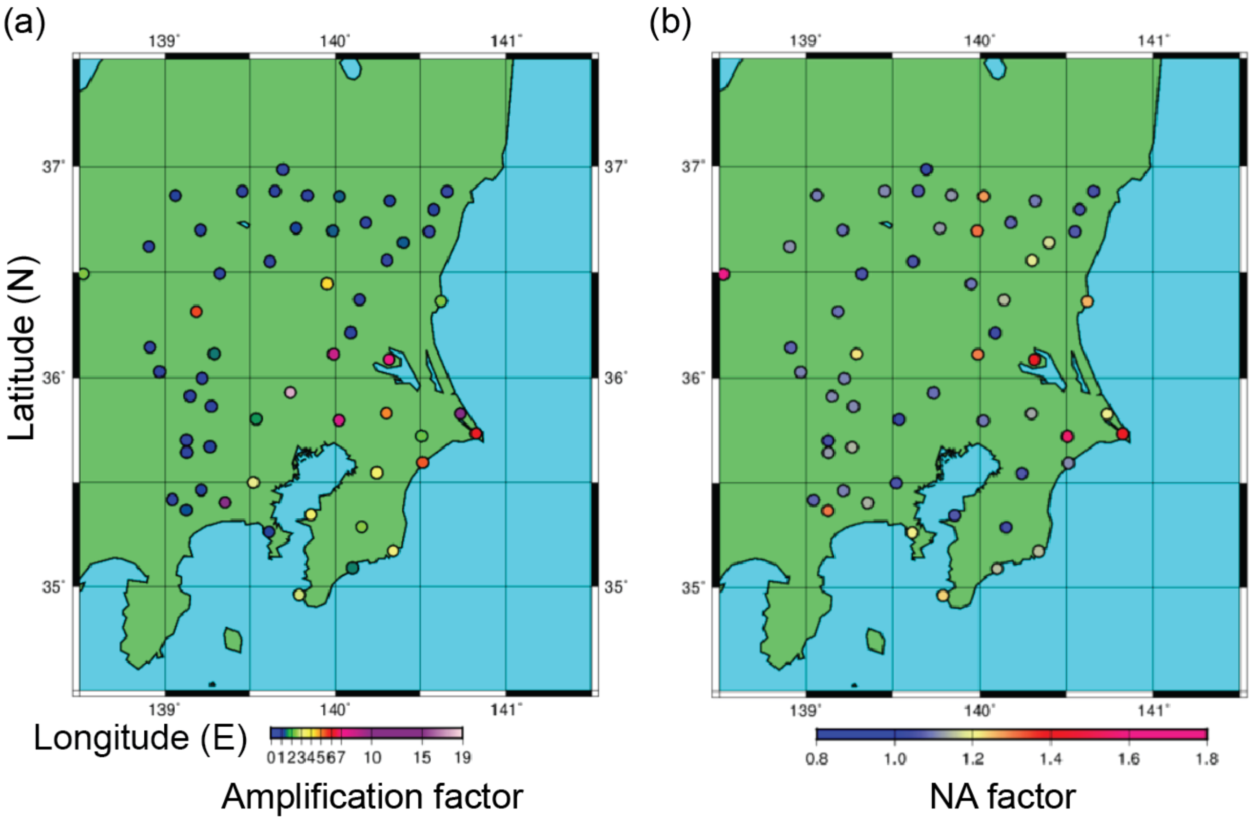

Fig. 1 (a) Amplification factors at KiK-net sites. (b) Normalized amplification factors.

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Variations in strength and predominant period of long-period ground motions around the northern Kanto sedimentary basin due to epicentral directions

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Introduction

In the Kanto sedimentary basin, long-period ground motions are frequently observed and those predominant periods are affected by the bedrock depth of sedimentary basin (e.g., Yoshimoto and Takemura, 2014). Furthermore, excitation of long-period ground motions varies by epicentral directions of earthquakes (e.g., Yuzawa and Nagumo, 2012). In spite of these observational findings, less well known are the excitation characteristics of Love and Rayleigh waves, which cause long-period ground motions in the basin. Thus, in this study, we analyzed horizontal and vertical waveforms collected from stations of K-NET, KiK-net, and SK-net to investigate the characteristics of strength and predominant period of long-period ground motions during earthquakes with different epicentral directions.

Analyzed earthquakes and analytic method

We analyzed eight shallow moderate-to-large earthquakes (Mw 5.8–6.9) having a wide coverage of epicentral directions. The CMT solutions of these earthquakes by F-net indicated that hypocentral depths were shallower than 8 km and source mechanisms were reverse or normal fault types. To analyze long-period ground motions which appeared after the arrival of S waves, we selected waveforms using the following recording conditions: a) at epicentral distances shorter than 150 km, waveforms recorded at least 100 s from earthquake origin time; b) at epicentral distances longer than 150 km, waveforms recorded over 150 s in total length or 200 s from earthquake origin time. We calculated Fourier spectra of velocity waveforms to investigate strength and predominant period of long-period ground motions observed in the Kanto basin.

Variations of long-period ground motions due to epicentral directions

Comparison between horizontal- and vertical-component Fourier spectra revealed that, for all earthquakes, the magnitude of horizontal amplitude spectra dominated over that of vertical amplitude spectra, and horizontal predominant period was longer than vertical one, suggesting the dominance of Love waves over Rayleigh waves in the Kanto sedimentary basin. As for the predominant period, clear bedrock depth changes were observed for both components: the deeper bedrock depth, the longer predominant period. In a strict sense, this relationship held only in the area where the bedrock depth was shallower than 2 km, but otherwise the predominant period became almost constant values (Horizontal: 6.3 s, Vertical: 4.8 s) in deep (> 2 km) bedrock area. These observations were also consistently explained by assuming the dominance of Love waves over Rayleigh waves.

Analysis of the amplitude and the predominant period of long-period ground motions during The Mid Niigata prefecture Earthquake in 2004 (NW event) and the earthquake in Hamadori region of Fukushima prefecture on April 11, 2011 (NE event) revealed that the observed spectral amplitudes were almost the same for these earthquakes but the predominant periods were clearly different between these earthquakes: predominant periods of horizontal- and vertical-component observed at deep (> 2 km) bedrock area were approximately 6.6 s and 5.2 s, respectively, for NW event, and were 5.6 s and 4.6 s, respectively, for NE event. This observation suggested that the excitation of both horizontal and vertical long-period ground motions was affected by the difference in epicentral directions.

Acknowledgement

The K-NET/KiK-net waveform data and the F-net CMT solution data were provided by the National Research Institute for Earth Science and Disaster Prevention, Japan. SK-net waveform data were

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provided by the Earthquake Research Institute at the University of Tokyo.

Keywords: long-period ground motion, Kanto sedimentary basin, variation due to epicentral direction, predominant period, surface wave

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Source Azimuthal Dependence of Long-Period Ground Motions in the Kanto Basin and the transition of time-history

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During the 2011 off the Pacific coast of Tohoku Earthquake, long-period ground motions were observed in the Kanto basin; therefore, long-period structures located in the Kanto basin were largely shook. Some articles (e.g. Yuzawa and Nagumo, 2012; Tsuno et al., 2012) pointed out that amplifications of long-period ground motions observed in the Kanto basin have the source azimuthal dependence by the data analyses on the main shock and aftershocks. Tsuno et al. (2012) reported that long-period ground motions whose periods were larger than 3 seconds has the characteristics of surce azimuthal dependence, using the ratio of the pseudo-velocity response spectrum on surface to that at borehole.
We have investigated the source azimuthal dependence in the Kanto Basin, by data of the observations and the simulations for 10 earthquakes occurred around the Kanto Basin (Noyori et al., 2015). As a result, we could confirmed the same tendency between the observations and the simulations that long-period ground motions larger than 3 seconds were largely amplified for earthquake located in in north-west (Niigata pref.) direction and south-west (Shizuoka pref.) direction. In this study, we investigated the transition of source azimuthal dependence in the time history, which are related to the propagation of seismic motions in the Kanto basin.

Keywords: Long-period ground motion, Source azimuth, Site effect, Kanto Basin

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Equivalent-Linear Site Response Analysis in the Kanto Plain

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The Kanto plain, the largest and most populated plain in Japan, is covered with thick marine sediments that can cause large amplifications of seismic waves during a big earthquake. The sediments thickness over the engineering base reaches to several hundred meters under the central part of Tokyo Metropolitan area. In this study, we evaluated the nonlinear site responses of layers between engineering base and free surface in the Kanto plain. We adopted an equivalent linear approach using DYNEQ program developed by Yoshida and Suetomi (1996) for the site response analyses. We use stochastic Green’s function method to generate synthetic waveforms from 16 hypothetical earthquake source models located in the crust, and on the interface or within the of subducting Philippine Sea Plate. The simulations were done between the seismic sources and the engineering base where shear-wave velocity is equal to 500 m/s. Synthetic waveforms on the engineering base were used as input motion in DYNEQ program. Shear modulus versus strain (G/G_0-γ) and damping versus strain (h-γ) relationships of Central Disaster Management Council of Japan (CAO) are recognized to express the dynamic shear deformation of soil (clay, sand, and gravel). Shallow shear-wave velocity structural models above the engineering base were also provided by CAO. Resultant waveforms on the free surface show a systematic dependence on the thickness of soft structures above the engineering base. Large amplifications are dominant at short periods above shallow soft sediments, whereas peak amplitudes shifted to longer periods for sites located above deep soft sediments. Nonlinear site effects, inferred by de-amplification of the site responses, were typically obvious at short periods of approximately 0.2 s and shorter. Predominant periods of the soil was calculated based on empirical relations and compared to those obtained from the spectral ratio. Both predominate periods show disagreement at sites where nonlinear site responses are expected. The large deformations are mostly concentrated in shallow 30 m of soil inferred from shear strain analysis. Our analyses showed considerable effects of nonlinear response of surface layers to large seismic inputs on the engineering base. Our results reconfirm the importance of nonlinear soil effect consideration in risk assessment of structures.

Keywords: Equivalent linear approach, Site effects, Tokyo Meteropolitan Area

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The Effects of Thick Sediments to Long-period Ground Motion in Northern China

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The study of ground motion is a cross research field between earth science and engineering science. Theoretical seismologists are more concerned about propagation path and the effect of seismic focus, while engineering seismologists are more concerned with the ground effect. Studies have shown that the western Taiwan coastal plain is influenced by long-period ground motion from the 1999 Chi-Chi, Taiwan, earthquake, and engineering structures with natural vibration long-period are damaged by strong surface wave in the western coastal plain. The thick sediments in the western coastal plain are the main cause of the propagation of strong long-period ground motion. The thick sediments similar to in the western coastal plain also exist in northern China.
It is necessary to research the effects of thick sediments to long-period ground motion in northern China. The numerical simulation of ground motion based on theoretical seismology is one of important means to study the ground motion. We will carry out the numerical simulation of long-period ground motion in northern China by using the existing tomographic imaging results of northern China to build underground medium model, and adopting finite fault source model for wave input. In the process of simulation, our previous developed structure-preserving algorithm, symplectic discrete singular convolution differentiator (SDSCD), is used to deal with seismic wave field propagation. Our purpose is to reveal the formation and propagation of long-period surface wave in thick sediments and grasp the amplification effect of long-period ground motion due to the thick sediments. It will lay the foundation on providing the reference for the value of the long-period spectrum during determining the ground motion parameters in seismic design.
This work has been supported by the National Natural Science Foundation of China (Grant No.41204046, 42574051).

Keywords: Thick Sediments, Long-period Ground Motion

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A multi-period inversion of broadband seismic waveforms for 3-D velocity structures

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A precise velocity structure model is necessary to predict long-period ground motions during large earthquakes and analyze source processes using long-period waves. Many studies have reported that 3-D velocity structures formed by sedimentary basins or accretionary wedges along subduction zones can significantly affect the generation and propagation of long-period seismic waves. In terms of including the various effects of the 3-D velocity structures, a waveform inversion for 3-D velocity structures using the time history of long-period ground motions is the most effective. These were several studies that estimated 3-D velocity structures by waveform inversions. Aoi (2002) proposed a method that estimates the 3-D depth of the boundary between sediment and bedrock. Iwaki and Iwata (2011) applied the method of Aoi (2002) to real data observed in the Osaka basin, Japan. Hikima (2006) formulated an inversion procedure for 3-D velocity structures, in which observed waveforms are initially inverted for layer thicknesses in 2-D cross-sections and a 3-D velocity structure model is subsequently constructed by interpolating the results of the 2-D inversions. In southern California, the estimations of the seismic velocity and the intrinsic attenuation were performed by the numerical simulations of wave propagation in combination with the adjoint method (e.g., Askan and Bielak, 2008; Tape *et al.*, 2010).

Seismic waveforms with a period range such as 2-20 s are often used to evaluate long-period ground motions. Thus, it is important to construct a velocity structure model which well reproduces the waveforms filtered over this period range. In this study, we attempt to develop a waveform inversion method for 3-D velocity structures that are responsible for broad-period ground motions. We first divide the inverted period range into multiple period ranges such as 10-20, 5-20, and 2-20 s. We start our inversion with the waveforms with only the longer-period range (10-20 s). The solution for the current period range is used as an initial guess for the next period range, which includes the shorter period (5-20 s). The inversion is continued until the period range matches the broadest period (2-20 s). The velocity structure model is composed of homogeneous layers, and the layer thicknesses are set as model parameters, just as Hikima (2006) did. The model parameters are estimated by solving a non-linear damped least-squares problem, which is an iterative procedure. In the inversion using only longer-period waveforms (10-20 and 5-20 s), we can use coarse inversion grids (e.g., Bunks *et al.*, 1995); in the inversion using the waveforms with the broadest period (2-20 s), a reasonable initial guess leads the iteration to achieve a fast convergence. Thus, our inversion procedure is better than conventional waveform inversions in terms of reducing the total number of 3-D forward simulations. Furthermore, we can stably estimate the model parameters for a complex velocity structure with multiple layers.

We calculate the partial derivatives with respect to model parameters using finite-difference approximation, where the difference between the unperturbed and slightly perturbed synthetic waveforms is taken. The synthetic waveforms are calculated by a 3-D finite element method with voxel meshes (Koketsu *et al.*, 2004; Ikegami *et al.*, 2008). We also use the modified Levenberg-Marquardt method to make the iteration stable. At each iteration, the model parameters are solved by the singular value decomposition of the Jacobian matrix. We performed several numerical experiments to confirm the validity of our inversion procedure. We will show the results and discuss the performance of the recovery of broad-period data as well as the optimal way to divide the inverted period range.

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Keywords: Velocity structure model, Waveform inversion, Broadband seismic waveform, Damped least-squares method, Non-linear problem

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Performance Check of the Velocity Structure Model of Oita Prefecture Using Strong Motion H/V and R/V Spectral Ratio

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S-wave velocity strucrure of Oita prefecture is checked using H/V and R/V spectral ratio analyzed with strong motion data observed with strong motion network operated by Oita Prefecture. See detail in our Japanese abstract.
Acknowledgement: This research has been done under the Comprehensive Research on the Beppu-Haneyama Fault Zone (FY 2014-2016) by MEXT, Japan. Strong motion data are provided by Oita Prefecture and NIED.

Keywords: H/V spectral ratio, R/V spectral ratio, three-dimensional velocity structure model

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Estimation of Subsurface Structure Using Receiver Function at Seismograph Observatory Site in Tottori Prefecture

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In this study, subsurface structures of strong ground motion observation sites in Tottori Prefecture were estimated from receiver functions at seismograph observatory sites. PS-P times were obtained from receiver functions of observation data and parameter of existing underground model (J-SHIS model etc.). The PS-P times were compared with both results at each site and subsurface structure models were estimated by adjusting the layer thickness of initial model. Theoretical receiver functions were calculated from subsurface structure by using Haskell matrix and subsurface structure models were estimated by comparison of both receiver function.

Keywords: Receiver function, Subsurface structure, Seismograph observatory site, Tottori Prefecture

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Exploration of Underground Structure and Analysis of Seismic data in Central Area of Tottori Prefecture

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An earthquake (in 1983, M6.2) which caused disasters in Kurayoshi City occurred in central area of Tottori Prefecture. In this study, microtremor and gravity survey were carried out to estimate underground structures in the target area. Furthermore, aftershocks were observed at temporary seismic observatories around focal region and the seismic data (include data of municipalities) were analyzed. S-wave velocity model, microtremor H/V spectrum and a gravity basement structure were obtained from underground explorations. Characteristics of seismic indexes of target observatories were understood from analysis of seismic data.

Keywords: Underground structure, Geophysical exploration, Seismic data, Central Area of Tottori Prefecture

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Estimation of Rayleigh Wave Phase Velocities around the Beppu Bay Area using Long-period Volcanic Signals

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We deployed a dense seismic array consisting of 12 broadband stations after late August 2014 around the Beppu bay area, Oita prefecture to investigate seismic velocity structure of deep sedimentary basin (Hayashida et al., 2015, JpGU Meeting). Around the same time of the installation, long-period volcanic tremors at Aso volcano (Kaneshima et al., 1996, Science) have been frequently generated [e.g. Sandanbata et al. (2015, JpGU Meeting); Matsuzawa et al. (2015, JpGU Meeting)] and our observation network clearly detected the corresponding signals. The characteristics of the detected signal are as follows: (1) the signal is dominant in the frequency range between 0.06 and 0.125 Hz, (2) the signal is particularly dominant in the vertical component, (3) the signal behaves much like Rayleigh wave, and (4) the signal propagates with a velocity about 3.2 km/s. As seismic interferometry analysis of observed seismic noise can yield surface-wave group velocities down to 0.2 Hz at the lowest due to small station-to-station distances (Hayashida et al., 2015, SSJ Fall Meeting), we utilize the abundant data for the volcanic signals to investigate surface-wave properties at lower frequencies and to validate deeper S-wave velocity structure around the bay. We selected 15 station pairs that have much smaller station-to-station distances compared to distances between Mt. Aso and the stations to assume plane wave-front propagation. Based on the phase differences of the band-pass filtered waveforms (vertical component) between two stations, we estimated Rayleigh-wave phase velocities in the frequency range between 0.05 and 0.12Hz at intervals of 0.001 Hz. The estimated phase velocities show dispersions and correspond well to those calculated from the existing crustal velocity structure model (Nishida et al., 2008, JGR) in the frequency range between 0.06 and 0.08 Hz (3.4-3.6 km/s) for most station pairs. On the other hand, at around 0.1 Hz, the estimated phase velocities show spatial variations reflecting complicated sedimentary structure beneath the area.

Acknowledgements:
This work has been done under the Comprehensive Research on the Beppu-Haneyama Fault Zone (FY2014-2016) by the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Keywords: Aso volcano, long period tremor, phase velocity, Rayleigh wave

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A method for constructing seismic velocity structure model for long-period ground motion evaluation - utilization of Rayleigh-wave dispersion information -

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Introduction

For the precise evaluation of long-period ground motions in the Tokyo metropolitan area, detailed sedimentary seismic velocity structure model of the Kanto Basin should be required. Recently, Yoshimoto and Takemura (2014) reported that, in the Kanto Basin, local sedimentary S-wave velocity structure in the vertical direction is practically characterized by using a simple three-parameter function (Ravve and Koren 2006). Takemura et al. (2015) demonstrated the effectiveness of this modeling in long-period ground motion simulations. Adopting this modeling technique, we propose a method for constructing a local sedimentary seismic velocity structure model by using Rayleigh-wave dispersion information from observed long-period ground motions and microtremor surveys, and check the effectiveness of our method based on numerical experiments.

Method for constructing sedimentary seismic velocity structure model

Suppose that the information on Rayleigh-wave phase velocity at a certain site is available from array analyses of long-period ground motions at long-period band (6-8 s) and from microtremor surveys at short-period band (1-3 s). The three-parameter function (parameters: S-wave velocity at the surface, S-wave velocity gradient in the vertical direction, and S-wave velocity increment at a sufficiently large depth) stated above could be reduced to a two-parameter function if we let the third parameter be equal to the S-wave velocity of bedrock (Yoshimoto and Takemura, 2014). Then, by adopting empirical relations among the density, P-wave velocity, and S-wave velocity, we can formulate inversion analysis of local sedimentary seismic velocity structure as a two-parameter problem, which is easily solved by using conventional grid-search technique.

Result of numerical experiments

We conducted a set of numerical experiments of our inversion method to confirm its effectiveness for the construction of sedimentary seismic velocity structure model. Using a sedimentary structure model of the Yokohama seismic observation well (Yamamizu 2004) as the test model, we investigated how many observations of Rayleigh-wave phase velocity are requited to obtain the precise inversion result. In our numerical experiments, for simplicity, we supposed that the Rayleigh-wave phase velocities were fully available at long-period band (6, 7, and 8 s) but limitedly available at short-period band (1 or 2 or 3 s). We used a software package developed by Herrmann (2013) to calculate the dispersion characteristics of Rayleigh wave.

Our numerical experiments demonstrated that when the Rayleigh-wave phase velocity at period of 1 s was available, the distribution of squared-residuals between input and calculated phase velocities showed a most localized pattern of the minimum residuals. This result indicates that, for the use of our two-parameter modeling technique, the information on Rayleigh-wave phase velocity at period of 1 s is very useful to estimate S-wave velocity at the surface. Based on our numerical experiments, we may conclude that the construction of local sedimentary seismic velocity structures for long-period ground motion evaluation could be easily carried out by our inversion method using Rayleigh-wave dispersion information from long-period ground motions and microtremor surveys.

In our presentation, we will discuss the noise stability of our inversion method and its estimation errors.

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Keywords: long-period ground motion, sedimentary structure, Rayleigh-wave, phase velocity

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Estimation of 3D S-wave velocity model of sedimentary layers in Kanto area, using microtremor array measurements

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We have engaged in estimation of subsurface structure models from seismic bedrocks to ground surfaces in Kanto area for the purpose of enhancing prediction accuracy of earthquake ground motions. In order to advance the subsurface structure models, microtremor surveys have been conducted at a lot of sites in Kanto plane for these several years. Senna et.al., 2015, improved the conventional subsurface structure models by using records of microtremor array and earthquake observation. In this study, in addition to the previous described data, we will report results of microtremor array surveys with ones registered in the microtremor database of NIED and so on.

Keywords: microtremor array observation, velocity structure

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Improvement of shallow subsurface structure models based on miniature and irregular array microtremor observations in Kanto Area

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In order to estimate damage caused by strong ground motions from a mega-thrust earthquake, it is important to evaluate broadband ground-motion characteristics in wide area. To realize it, it is necessary to sophisticate subsurface structure models on which shallow and deep ones are integrated. Therefore, we have ever collected as many data as possible obtained by boring and microtremor array surveys, and then have modeled subsurface structures from seismic bedrocks to ground surfaces.

In this study, we focus on advancement of shallow subsurface S-wave velocity structures, especially around engineering bedrocks (Vs300~500m/s layers), in Kanto Area, including Tokyo. We have conducted miniature and irregular array observations at a great deal of sites in Kanto plane since last year. By using these observation data, 1-D and 2-D shallow subsurface velocity structures are estimated. Then, based on these models, the initial geological models are verified and modified if necessary.

Keywords: shallow subsurface structure, velocity structure, miniature array, microtremor

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An examination of the relation between the distribution of microtremor Horizontal-to-Vertical spectral ratios and the F distribution

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The distributions of microtremor Horizontal-to-Vertical Spectral Ratios (HVSR) have been investigated, with a special attention to the relation with the F distribution, on the basis of three types of microtremor waves: simple stationary waves numerically calculated with random phases, realistic waves numerically simulated based on an elastic theory and a subsurface velocity structure, and observed microtremor waves. The statistics D of the Kolmogorov-Smirnov (KS) test is used as a measure of the discrepancy between the distributions. Our simulations estimating HVSR of stationary waves with random phases indicated that the larger the circular variance of the propagating directions of microtremor waves becomes, the more a distribution of HVSR approaches the F distribution. Thus, the degree of the discrepancy from the F distribution depends on a microtremor wavefield. The analyses of realistic-simulated waves and observed microtremor waves revealed that the realizations of D took values between 1.5 and 6 % when the sample size was 3000. Since a critical value of the test lied in this range, the results of the KS test could be changed by incidental scattering. The above results indicate that the lower limit of D can be a several percent or less when the sample size is adequately large, and that a concrete value of D, as well as the results of the goodness of fit test, can depend on either biases or fluctuations in the propagating directions of microtremor waves.

Keywords: microtremor, H/V, probability distribution

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Microtremor array survey with spatial autocorrelation technique of Kazo lowland in Saitama prefecture,Japan

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We have conducted microtremor array survey with spatial autocorrelation (SPAC) techniques to estimate deep S-wave velocity structures up to 3,000 meters depth of Kazo lowland in the northeast of Saitama prefecture.
Three types of SPAC arrays, each of radii is 100m, 300m and 600m, have been deployed on the ground surface at observation sites and we have conducted microtremor observations during about one hour. Eleven sites in total have been spread out over region of approximately east-west 20km by north-south 15km. Phase velocity dispersion curves of fundamental-mode Rayleigh waves about 0.2 Hz to 1.5 Hz have been acquired.
S-wave velocity structures have been estimated through inversion analysis of dispersion curves with genetic algorism (GA) and initial structure models have been diverted from models that had been made for an earthquake disaster prevention plan.
We have estimated one dimensional S-wave velocity structures for all of eleven sites and have made comparison the results with existing explorations. The results are generally consistent, details are however assumed that require minor modification of existing models.

Keywords: Microtremor survey method, Spatial autocorrelation technique, S-wave velocity structure

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Microtremor chain array survey across the abnormal damaged zone of the 1946 Nankai Earthquake in the northern part of the Izumo Plain, Taisha-cho, Izumo City, Shimane Prefecture, Japan.

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An abnormal severe damaged zone of the 1946 Nankai Earthquake was observed along the northern edge of the Izumo Plain, Taisha-cho, Izumo City, Shimane Prefecture. In this study, we carried out a microtremor chain array survey across the damaged zone for imaging the detailed surface profile of the damaged zone. Correlating with previous geologic data by using pseudo-S-wave velocity and *N* value, the phase velocity profile of the present survey demonstrates a buried terrace at approximately 11 meter deep as an unconformity between Pleistocene and Holocene deposits. At the center of the survey line, a buried fossil valley cutting the buried terrace was clearly recognized. It implies that the severe damage of the earthquake might be affected by the thickened soft sediments at the buried fossil valley.

Keywords: microtremor chain array, the 1946 Nankai Earthquake, Izumo Plain

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Estimation of Bogota (Colombia) basin velocity model from microtremors array measurements for strong motion simulations

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Bogota a megacity with almost 8 million inhabitants is prone to a significant earthquake hazard due to nearby active faults as well as subduction megathrust earthquakes. The city has been severely affected by many historical earthquakes in the last 500 years, reaching MM intensities of 8 or more in Bogota. The city is also located at a large lacustrine basin composed of extremely soft soils which may strongly amplify the ground shaking from earthquakes. The basin extends aproximately 40 km from North to South, is bounded by the Andes range to the East and South, and sharply deepens towards the West of Bogota. The city has been the subject of multiple microzonations studies which have contributed to gain a good knowledge on the geotechnical zonation of the city and tectonic setting of the region. In order to construct a detailed velocity model of the basin we conducted 68 small to medium size microtremors arrays measurements (radius from 60 cm to 50 m) at 26 sites within the city, and two large arrays measurements at the central part of the basin (radius of 500 m and 1000 m). We calculated dispersion curves and inferred velocity profiles at all the sites. Our velocity profiles for the shallower sediments are characterized by a wide variability in Vs30 whose values range from 80 ~ 150 m/s in the northern and central part of the basin, and 120 ~390 m/s in the southern part. Our velocity models reached values of Vs=2000 m/s at a 2 km depth at the central part of the basin, but previous models suggest that the basin depth may largely increase further west. Our preliminar results indicate a sharp boundary in shallow S wave velocities between very soft sediments North of the basin and harder sediments to the South. This striking difference appears to have a strong correlation with the very large water content of the shallower soils (clays and silts) to the North as compared to the small water content of soils (gravels and sands) to the South. Our initial results indicate the need of denser microtremors measurements within the city by including large arrays that allow to characterize in detail the geometry of the basin depth.

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Keywords: Soil velocity model, Strong motion simlation, Bogota basin

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The strong resemblance between Fourier Spectrum and Phase difference Spectrum of the Seismic Wave.(Science of Form)

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1.none

1.The phase difference Spectrum and The Phase Wave of the seismic wave.

Fig-(1). Show “The relationship between the phase difference spectrum and the phase wave”. Please refer to reference (3). Find the phase difference Spectrum from the phase wave on the right -hand side, the peak position and added an expanse state of Spectrum are in perfect harmony accord. In short (in other words), in case of the frequency of the phase wave is high, the shape of the normal distribution of the phase difference spectrum is build up sharp. And in the case of large frequency get a flat normal distribution of spectrum. This phenomena stand up all right frequency is high or low. Of course this phenomena is reversible was stated reference (3).

I shall state a next item 2, the seismic wave and this phase wave should be a one-to-one relation. And still more the Fourier spectrum of the seismic wave and the phase difference Spectrum should be a one-to-one relation.

2.The Fourier Spectrum and the normal distribution of seismic wave.

We think that the case of the epicenter length is becoming shorter little by little. The large epicenter length to get along with, the seismic wave energy is dispersed in every direction and still more had died out. As a result, the shape of the Fourier spectrum don’t become a hill shape and happened occasionally a pointed shape. The shorter epicenter length to get along with, the shape of the Fourier spectrum of seismic wave is formed a hill and soon are considered the shape of the normal distribution.

Reference. “Earthquake” written by Seismologist KIYOO Wadachi. The Chuukou Library. (A pocket edition) 1933 and 1993(reprint) p.99

“In the near area to the epicenter, the earthquake have very sharp motion. In many case, intense vertical motion happens in the early shocks of an earthquake. The longer the epicenter length little by little, vibration of seismic wave become slow little by little and becomes superior in a horizontal vibration.”

The shape of this normal distribution has flat hill and besides has large frequency of the peak of the hill. But get shorter little by little, the shape of the normal distribution (or Bell type) becomes sharp and becomes short frequency.

Moreover make the short epicenter length, we shall study the normal distribution theory (Gaussian distribution, Mt.Fuji-type or Bell type) of probability and statics.

In the reference (4), I have explained the KdV equation.(literature (3),(4))

Abstract

1. The shorter epicenter length shorter, the shape of the normal distribution becomes sharp. And this frequency too becomes small. The case of the epicenter length is large, the normal distribution of spectrum of seismic wave was not build up. Only build up a scattered peak.

2. On the case of the phase wave and the phase difference spectrum, the same phenomenon too come into being.

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Keywords: Fourier Spectrum, Phase difference spectrum, Seismic wave, Phase wave, KdV equation, Solitary wave

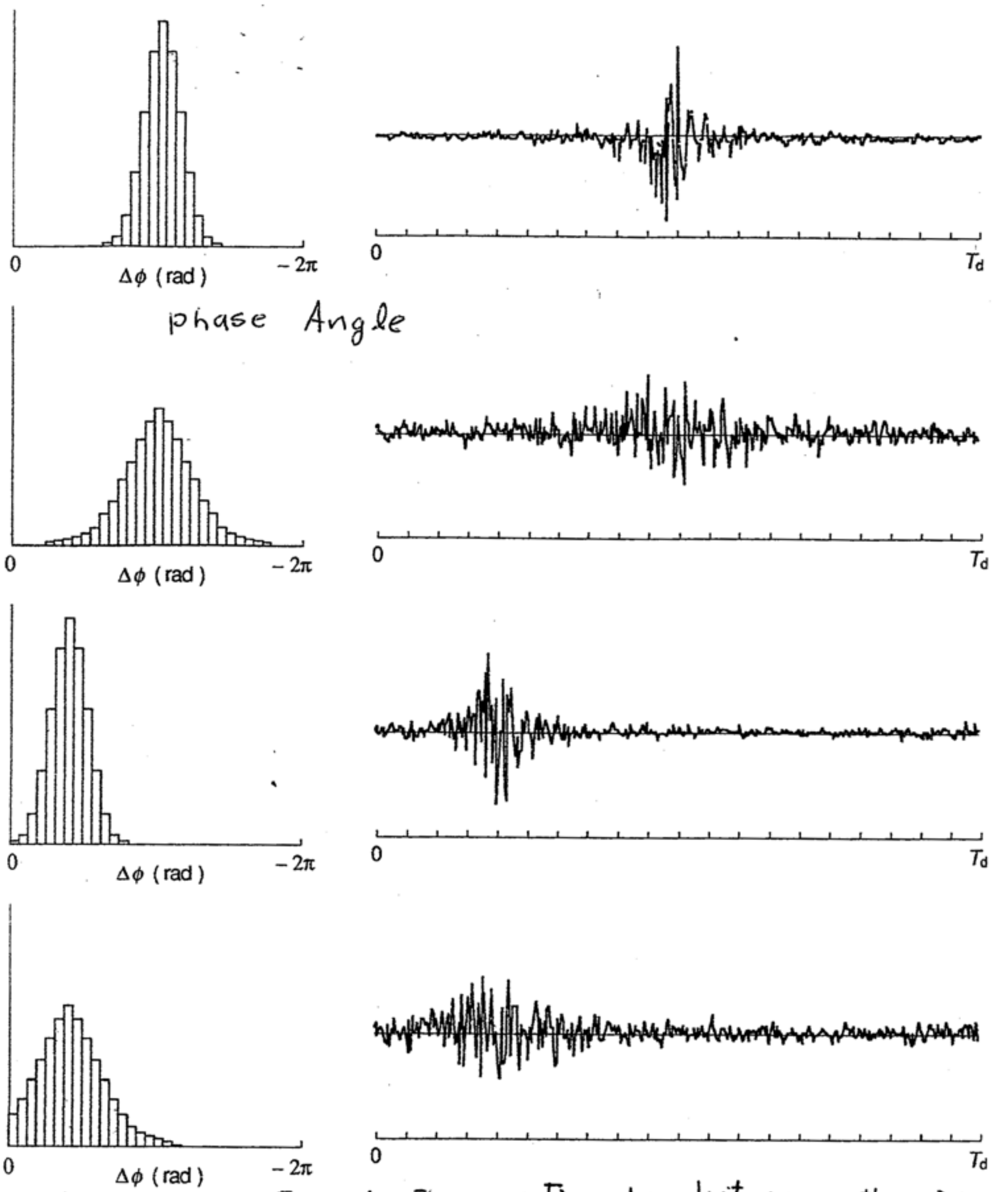

Fig-1 The rerationship between the Phase difference Spectrum and the Phase Wave.
~~図1-23~~ 位相差分スペクトルと位相波の関係

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