Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SSS35-01 Room:502 Time:May 2 14:15-14:35

On the generalization of the SPAC method and the development of a CCA method

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Introduction

Microtremor array methods refer to techniques for estimating subsurface velocity structures from the dispersion of Rayleigh-wave phase velocities obtained through array analysis of microtremors. Methods for analyzing Rayleigh-wave phase velocities include two major constituents: the spatial autocorrelation (SPAC) method [Aki, 1957] and the frequency-wave number spectral (FK) method [Capon, 1969]. SPAC method excels the FK method in the overall analysis efficiency, when account is taken of the requisite number of seismic sensors and the breadth of the wavelength ranges eligible for analysis [Okada, 2003]. The SPAC method, in addition, is intrinsically usable with a two-sensor seismic array [Aki, 1957], a potential that has received reappraisal during the past decade. Given this context, the SPAC method in recent years has not only come to be used more often, but has also seen progress in theoretical studies of its applicability.

Generalization of the SPAC method and the development of a CCA method

In our case, Cho et al. [2006] generalized the Aki's theory following Henstridge[1979], describing generic formulae to analyze a circular array of three-component microtermors on the basis of the theory of stationary random processes. The generic theory provided a basis for constructing various methods to efficiently analyze Rayleigh- and Love-wave phase velocities, Rayleigh-wave ellipticities, and power partition ratios of Rayleigh to Love waves. It also provided a theoretical foundation to examine applicability conditions and optimal observation durations for two-sensor SPAC methods.

The centerless circular array (CCA) method [Cho et al., 2004] represents one method on the basis of the generic theory to analyze phase velocity of Rayleigh waves. The CCA method is characterized, among other things, by its applicability to an array of three seismic sensors in irregular configuration. It is also characterized by superior analytic performance in long-wavelength ranges. Methods have been proposed to evaluate noise levels, which can negatively impact its analytic performance, in terms of signal-to-noise (SN) ratios and to compensate for the effects of noise.

In the first half of the presentation, the above history will be described after a simple explanation of the general features of microtremor array explorations.

Development of miniature array analyses for shallow surveys

In the second half, the situation on the miniature array analyses based on the CCA method will be reported. ”Miniature array analyses” involves 15-min microtremor measurement sessions using very small seismic arrays, 1 m or less in radius, to obtain the dispersion of Rayleigh-wave phase velocities corresponding to depths of several tens of meters, and sometimes more than 100 m, beneath the surface. In addition to this feature, the analysis results are accompanied with quality control factors. In the last year, we dealt with the following problems so as to put the miniature array analysis into practical use: (i) What is an appropriate way to deal with analysis results of limited quality and dubious reliability in general? (ii) What is a better way to pursue the efficiency of surveys, including the step of estimating subsurface structures after the dispersion curve is obtained?

In the presentation, I will report the solution for this problem on the basis of the experience, the automatization of the analysis procedure (Cho et al., 2014; Senna et al., 2014), and a plan to release a new BIDO package (https://staff.aist.go.jp/ikuo-chou/bidodl.html) to draw 2D S-wave sections by miniature array analysis.

Acknowledgement The outcomes in the first half were obtained in the collaborative investigation with Dr. Taku Tada and Prof. Yuzo Shinozaki. Those in the second half were obtained in the collaborative investigation with Dr. Shigeki Senna and NIED, and through discussions with the members of the microtrmor working group.

Keywords: Microtremor, velocity structure, surface waves, phase velocity, exploration method, array

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SSS35-02 Room:502 Time:May 2 14:35-14:50

Detection of Rayleigh wave and Love wave detection from microtremor array measurements

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Microtremor array measurements are considered to be one of the most practical ways to explore the S-wave velocity structures for the seismic hazard evaluation. As seen in many articles (e.g. Horike, 1985), the Rayleigh-wave dispersive characteristics have been derived from vertical components to model the S-wave velocity structures. On the other hand, the detection of Love-waves from horizontal components seems to be limited in very few literatures (e.g. Yamamoto, 2000), because horizontal components of microtremors are composed of the Love-waves and the Rayleigh-waves and the separation of two different kinds of surface waves is usually considered to be difficult.

As representative methods to analyze the microtremoer array records, the FK spectral method proposed by Capon (1969) and the spatial autocorrelation (SPAC) method by Aki (1957) have been used. Both methods have been extended to treat three-component data and detect the Love-wave as well as the Rayleigh-wave: the FK spectral method by Saito (2007) and the SPAC method by Okada and Matsushima (1990) and Yamamoto (2000), respectively. It is considered to be significant to apply these extended methods to observed data in various test fields. In our previous study, we carried out microtremor array measurements at Takasu area in Kochi city, south-west Japan on November 2010. We used two circular arrays with radii of 50 m and 100 m simultaneously, and successfully detected dispersive characteristics of both Rayleigh-waves and Love-waves in a frequency range between 1.2 to 3.8 Hz (Ohori et al. 2013). In analyses of observed array records, we used two kinds of the FK spectral methods: Capon's technique (1969) applied to vertical component and Saito's one (2007) to horizontal components.

To make a better understanding about characteristics of microtremors for the targeted area and obtain surface wave dispersive characteristics in more higher frequency range (up to 6Hz), we additionally conducted a few smaller array measurements on March 2013, using 4 sets of three-component portable seismometers which compose a circular array with a radius varying step-by-step from 50 m to 25 m and 12.5 m. In our study, results from newly observed data are reported and discussed. Phase velocity results were obtained from FK spectral method for vertical and transverse components. We also applied the SPAC method (Yamamoto, 2000) and compared the estimated phase velocity results from the SPAC method with those from the FK spectral method. The SPAC method provided that the energy power ratio of Love-waves in horizontal components distributed within 40-70% in a frequency range between 1.4 to 6 Hz.

Keywords: microtremor array measurements, FK spectral method, SPAC method, Rayleigh-wave, Love-wave

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SSS35-03 Room:502 Time:May 2 14:50-15:05

Estimating composition of ambient noise from three-component records at Tono array

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Ambient noise methods have become common tools to explore and monitor subsurface structure. However, effective uses of ambient noise should stand on the knowledge of a nature of ambient noise. In order to reveal the composition of ambient noise quantitatively, we extend the SPAC method to body wave incidence. Applying the extended SPAC method to the observation at Tono array, northeast Japan, we shows a good agreement between the theoretical cross spectra and the observed cross spectra. By fitting the theoretical cross spectra to the observed cross spectra, we estimated the composition ratio of Rayleigh, Love, and P waves. The characteristics of the composition ratio show a significant change at 1 Hz. While the P wave composition in total power is 5-15% and the lowest one below 1 Hz, the P wave composition suddenly increases above 1 Hz and reaches 50% and the highest one in those of the three wave modes. The change at 1 Hz is attributed to attenuation of high-frequency surface waves because the decay rate of the absolute value of power spectra of surface waves gets steeper around 1 Hz as compared with the constant decay of P wave. We also examine the temporal variation of the composition of ambient noise. Whereas power spectrum of each mode shows long-term and short-term temporal variations coincident with offshore significant wave height, the ratio between power spectra varies little with time. The constant composition ratio suggests that the mechanism and the source-receiver distance are stable in time. Accordingly, near coastal region is a possible region of the dominant source of the observed ambient noise. For applications of ambient noise, we should take account of the composition of ambient noise.

Keywords: ambient noise, SPAC, three-component array observation

Japan Geoscience Union Meeting 2014
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SSS35-04 Room:502 Time:May 2 15:20-15:35

Toward Earthquake Ground Motion Prediction using the Onshore-Offshore Ambient Seismic Field in Subduction Zones

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Ground motion prediction is critical to evaluate the seismic hazard specially in high seismicity areas as Japan. A source of particular concern is the complex geological structures as sedimentary basins which can trap and amplify seismic waves. It has been proved by Prieto and Beroza (2008) that reliable phase and amplitude of the impulse response functions can be extracted by deconvolution of the ambient seismic field recorded by two on-land stations without any pre-processing. This approach has the great advantage to predict accurate ground motion of moderate earthquakes at periods longer than 4 s without the need of any external information about the velocity structure. However, this method allows only to recover relative, rather than absolute, amplitudes. To retrieve the corresponding Green's functions, impulse response amplitudes need to be calibrated using records of an earthquake which happened close to the "virtual" source. Moreover, as surface-to-surface Green's functions are extracted, some mismatches are observed between Green's functions and the earthquake records. This feature is due to the fact that depth and focal mechanism of the event are not taken into account. Despite of these disadvantages, accuracy of the predicted ground motion is high and such long-period ground motion investigation is critical to carried out seismic hazard assessment for high-rise buildings, bridges, or oil tank having long-period resonance. In this study, we use this technique in subduction zones to extract vertical-to-vertical component of the Green's functions between seismic stations located on the ocean bottom and on-land Hi-net stations. The target region is located in the Tokai/Tonankai areas where two submarine cable-based sea-bottom seismographic observation systems have been deployed by the Japan Meteorological Agency (JMA). We use one month of noisy data recorded in January 2013 to compute the Green's functions. The choice of these data is motivated by a strong signal-to-noise ratio of the causal part of the Green's functions during this period. We validate this approach by comparing computed Green's functions with offshore moderate earthquake (Mw ~5) records in the Nobi sedimentary basin where the Nagoya city is located. As megathrust earthquakes are expected in this area, we extrapolate our results to predict magnitude Mw ~6 or larger earthquake ground motions using the scaling law of seismic spectrum developed by Aki (1967). These results are finally compared to long-period ground motion prediction equations to evaluate their validity.

Keywords: Ground motion Prediction, Ambient seismic field, Subduction zones, Low frequency, Deconvolution

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SSS35-05 Room:502 Time:May 2 15:38-15:57

Review of study on microtremors and application for subsurface structure modeling

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[1]OYO

The study on microtremors start by Kanai(1954). In his study, the relation between the subsurface structural model and the predominant period.

The method of the spectral ratio of two sites are devises. The influences source and path is removed.

From the 1980s, using spectral ratio between horizontal and updown component the subsurface structural model was estimated(Arai and Tokimatsu,2005). They assumed the microtremor consists by surface waves. On the other hand Nakamura(1988) assumed the microtremor consists by the SH waves.

H/V spectral ratio is using earthquake damage assumption investigations. Using H/V spectral ratio and phase velocity of Rayleigh wave, R/V spectral ratio of earthquake ground motion, the subsurface structural model from several meter to several kilometer depth are estimated in the Kanto area.

Keywords: Microtremors, Spectral ratio, S-wave structural modeling

Japan Geoscience Union Meeting 2014
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SSS35-06 Room:502 Time:May 2 16:15-16:30

Geological Interpretation of a Liquefied Area by 'i-Bido': A Case Study in Urayasu City, Japan (2)

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The Great East Japan Earthquake that occurred in 2011 off the Pacific coast of Tohoku caused the formation of two long cracks (crack 1 and crack 2) at Urayasu High School in Chiba Prefecture, Japan. Iwamoto et al. (2014) classified the survey area into different parts by examining the reclamation history and found the following three areas: A, 'Kaimenka-tochi'*; B, reclaimed land from dredged seabed deposits; and C, the embankment and its surrounding zone. Crack 1 was situated between areas A and B, and crack 2 was between areas B and C.

Based on the investigation, the authors conducted micro-tremor observations at the three reclaimed land areas and Alluvial area. These measurements were conducted to reveal the area's geophysical aspects and to extrapolate three-dimensional data of the subsurface geology from two-dimensional data. At each measurement position, the results of micro-tremor observation were analyzed to give H/V spectra and the relationship between the site's geology and physical data. Field measurements of micro-tremors were performed with JU310, which was designed by the National Research Institute for Earth Science and Disaster Prevention. Measurements and analysis were performed using the i-Bido system (Senna et al., 2011), named after the Japanese word for micro-tremor, which was designed by the same institute.

Analysis revealed that the micro-tremors in areas A, B, and C had clear peaks at 1 Hz or slightly higher. This result corresponds to the impedance ratio at the boundary between the Holocene and Pleistocene deposits. Additionally, the micro-tremors observed at area B, which contains land reclaimed in 1965-1971, had peaks from approximately 4-5 Hz. These peaks were not observed or were unclear in areas A and C. For both crack 1 and crack 2, the peak was clear on one side but not on the other. The interval across a crack was only a few meters; therefore, these peaks depend on the impedance ratio between the silt bed, which was reclaimed by dredging from the seafloor, and the Holocene deposits. Additionally, the Nd-value**of the silt bed was 0, as determined by a survey of the subsurface geology.

The analytical results determined using i-Bido supported the physical aspect put forth by Iwamoto et al. (2014) as the reason and mechanism by which the two cracks formed. Each frequency peak also showed the individual geological unit in the reclaimed bed, further supporting Iwamoto et al. (2014). The i-Bido system was very useful for analysis of the relationship between the site's geology and physical characteristics and for extrapolation of three-dimensional data from two-dimensional data. The authors hope that the methods discussed here will aid the progress of disaster prevention.

*'Kaimenka-tochi' means land below sea level literally. Before reclamation, it was located in front of seashore, and it was in the possession of the private owner. and was used to reed cultivation etc.

**Nd-value is brought by Dynamic Cone Penetration Test, which has the following conditions: a slide hammer with a weight of 5kg falling through a distance of 50cm, and diameter of 2.5cm cone. The number(i.e. Nd-value) of blows needed for the cone to penetrate each 10cm is recorded.

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References:

Hiroshi IWAMOTO, Masashi HIGASHI, Shigeo HIGUCHI, Akira INADA, Akihide ITO, Satoshi KAMIKASEDA, Kenichi KAWASAKI, Keiko KUSUNOKI, Shinji SATO, Shoichi SHINADA, Kazuyuki SUENAGA, and Takumi WATANABE (2014) Recent Geological Interpretation of Liquefied Area: A Case Study in Urayasu City, Japan(1). Japan Geoscience Union Meeting 2014.

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Keywords: liquefaction, crack, micro tremor, i-Bido, Urayasu, reclaimed land

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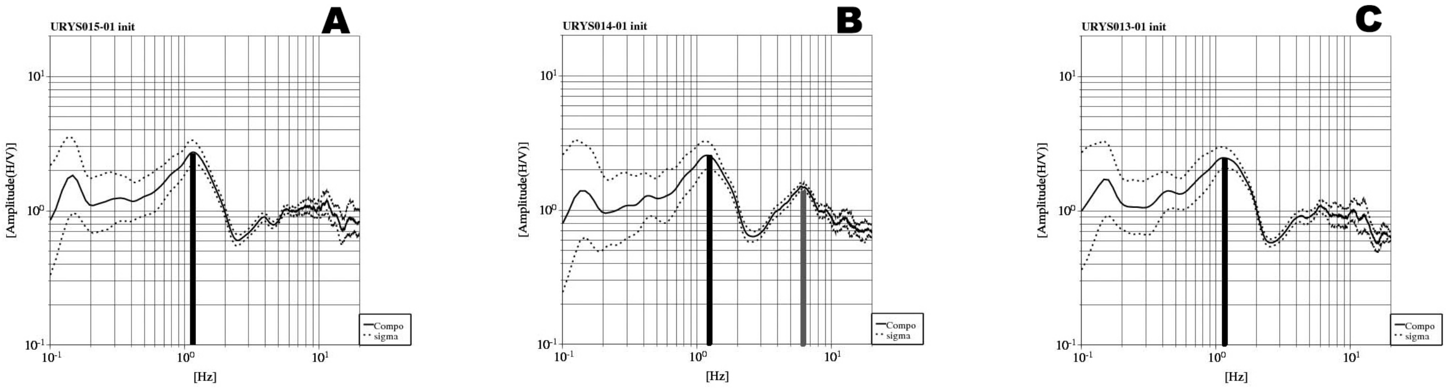

Fig.1 H/V Spectra of A, B, and C Areas

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SSS35-07 Room:502 Time:May 2 16:30-16:45

H/V Spectral Ratios for Both Microtremors and Earthquake Motions and Interpretation based the Diffuse Field Theory

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Horizontal-to-vertical spectral ratios (HVRs) of microtremors have been traditionally interpreted theoretically as representing the Rayleigh wave ellipticity or just utilized a convenient tool to extract predominant periods of ground. However, based on the diffuse field theory (Sanchez-Sesma et al., 2011) microtremor H/V spectral ratios (MHVRs) correspond to the square root of the ratio of the imaginary part of horizontal displacement for a horizontally applied unit harmonic load and the imaginary part of vertical displacement for a vertically applied unit load at the same position.

The same diffuse field concept leads us to derive a simple formula for earthquake HVRs (EHVRs), that is, the ratio of the horizontal motion on the surface for a vertical incidence of S wave divided by the vertical motion on the surface for a vertical incidence of P wave with a fixed coefficient depending on the bedrock wave velocity (Kawase et al., 2011). The difference of EHVRs from MHVRs comes from the fact that primary contribution of earthquake motions would be of plane body waves. Traditionally EHVRs are interpreted as the responses of inclined SV wave incidence only for their coherent S wave portions.

Before the advent of these compact theoretical solutions, EHVRs and MHVRs are either considered to be very similar/equivalent, or totally different in the previous studies. With these theoretical solutions we need to re-focus our attention on the difference of HVRs.

To that end we have compared HVRs at several dozens of strong motion stations in Japan. When we compared observed HVRs we found that EHVRs tend to be higher in general than the MHVRs, especially in higher frequencies than their fundamental peaks. As previously reported, their general shapes share the common features. Especially their fundamental peak and trough frequencies show quite a good match to each other. However, peaks in EHVRs in the higher frequency range would not always show up in MHVRs. When we calculated theoretical HVRs separately at these target sites, we found that the underground structures that are optimized for EHVRs would not explain perfectly MHVRs.

So we invert underground structures which can explain both EHVRs and MHVRs at the same time based on the different theoretical formula. Using the hybrid heuristic algorithm primarily based on the GA method with generation-dependent probability, we successfully obtain the detailed S-wave velocity structures for these investigated sites. The proposed method using HVRs is quite robust to obtain S-wave velocity structures that can be used quantitative simulation of strong motions at the target sites.

Keywords: microtremors, strong motion, diffuse-field theory

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SSS35-08 Room:502 Time:May 2 16:45-17:00

The Effect of the Basin Edge to the Directional Dependent Horizontal-to-Vertical Spectral Ratios of Microtremors

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Based on the diffuse field theory (Perton et al., 2009), Horizontal-to-Vertical (H/V) spectral ratios of microtremors (or ambient noise) correspond to the square root of the ratio of the imaginary part of horizontal displacement for a horizontally applied unit harmonic load, Im[G_{11}] and/or Im[G_{22}], and the imaginary part of vertical displacement for a vertically applied unit load, Im[G_{33}], where both the loads and receivers are at the same point on the free surface (Sanchez-Sesma et al., 2011). This theory can be applied to a site where the subsurface structure cannot be considered as sufficiently flat, horizontally layered (i.e., Im[G_{11}] /= Im[G_{22}]), and lateral heterogeneity exists, and the H/V spectral ratio of microtremors can be derived by the square root of the Im[G_{11}] and/or Im[G_{22}] and Im[G_{33}] (Matsushima et al., 2014).

The authors have shown that by using a numerical method such as the 3-D Spectral Element Method (SEM) (e.g., De Martin, 2011) to calculate the Green's functions from 3-D wave propagation analysis using a 2-D basin structure, it is possible to qualitatively simulate the significant directional dependency that can be seen in H/V spectral ratios of microtremors observed at sites on Uji campus, Kyoto University. The NS/UD has higher peak amplitude and EW/UD has higher peak frequency. The H/V spectral ratios derived from numerical analysis using Green's functions calculated for a simple 2-D basin model with one layer over bedrock show that the observed H/V spectral ratios are qualitatively simulated (Matsushima et al., 2014). Also, Matsushima et al. (2014) has shown that the shape of the H/V spectral ratio is distorted at sites close to the basin edge. This is an indication that if we observe microtremors at several sites close to the assumed basin edge, there may be possibility to identify the shape of the basin edge in detail.

In this study, we focus on the effect of the basin edge to the H/V spectral ratios and study the relation between the basin edge shape and the difference between NS/UD and EW/UD by simulating the H/V spectral ratios at sites close to the basin edge by numerical calculation. We consider a simple 2-D basin model with one layer over bedrock and change the shape of the basin edge. Also, we made micorotremor observation for two line arrays orthogonal to the 2-D basin in Uji and found that the observed H/V spectral ratios show the characteristics assumed from the numerical analysis.

From these results, we can see that the condition of the basin edge changes the H/V spectral ratios drastically at sites close to the basin edge. If we accumulate the relation between the shape and condition of the basin edge to the shape of the H/V spectral ratios in two orthogonal horizontal directions, we will be able to use the information from the observed H/V spectral ratios of microtremors to determine the basin edge shape.

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Keywords: Microtremor, H/V Spectral Ratio, Diffuse Field, Heterogeneity, Velocity Structure