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

Japan Geoscience Union Meeting 2014
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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

SUZUKI, Haruhiko[1*]

[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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[1]Chishirodai high school, [2]JAPEX, [3]No affiliation, [4]Chiba-kita High school, [5]Kanto Natural Gas Development Co., Ltd, [6]NTC Consaltants Co., Ltd., [7]Chiba-nishi High school, [8]Urayasu high school, [9]Earth System Science Co., Ltd., [10]NIED

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.

Acknowledgements

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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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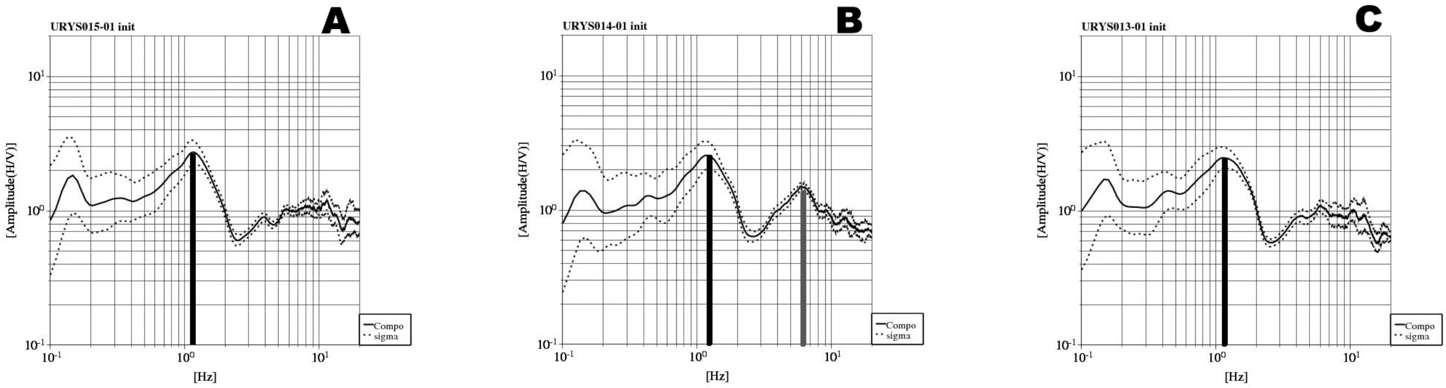

Fig.1 H/V Spectra of A, B, and C Areas

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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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[1]DPRI, Kyoto University, [2]Risk and Prevention Division, BRGM, [3]School of Engineering, Kyoto University, [4]Institute of Engineering, UNAM

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

SSS35-P01 Room:Poster Time:May 2 16:15-17:30

Sophistication of microtremor methods to survey shallow structures, PartI: Development of automatic reading algorithms

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[1]National Institute of Advanced Industrial Science and Technology, [2]National Research Institute for Earth Science and Disaster Prevention

We have been seeking an efficient way to maximize the potential of the microtremor methods for shallow surveys. It is considered that a practical approach has been gained in the observation by the development of portable seismometers (Senna, 2006, 2012) and by the finding of the full usability of the data obtained by a miniature array (radius $<$1 m), optionally together with a small irregular-shaped array (radius less than 10 m) consisting of three seismometers (Cho et al., 2013a).

As an efficient way to infer an S-wave velocity structure, we consider that a classical, simple profiling method (SPM), where a dispersion curve is directly converted into an S-wave velocity structure (e.g., Heukelom and Foster, 1960), is a good scheme from a view point of simplicity, thus, the balance between the efforts and the information to be extracted. It is true, however, that we frequently like to increase to resolution. Facing this dilemma, we suggested a simple tool "H/V depth conversion" (Cho et al., 2013). We found that the use of an H/V depth conversion followed by a simplified inversion method (SIM) of Pelekis and Athanasopoulos (2011) can in fact increase the resolutions (e.g., Senna et al., 2013; Yoshida et al., 2013).

The current problem is to further promote the efficiency in the data processing procedure. A visual reading of analysis results, which we take at the current time, is time consuming to deal with a vast mount of microtremor data, now obtainable by a streamlined observational procedure. The reproducibility and biases constitute other kinds of problem of visual reading.

To address this problem, we invented the following automatic-reading algorithms. We applied them to observed data consisting of multiple arrays along a measurement line. As the results, natural images of two-dimensional S-wave velocity sections were obtained, not considerably different from the one obtained by visual readings (Senna et al., 2014).

Automatic readings of phase velocities

Let us suppose that multiple dispersion curves have been obtained by either multiple arrays or multiple analysis methods (i.e., nc-CCA, CCA, and SPAC methods) at a single observation point. In the first step, apply the following procedure to each dispersion curve. (i) Divide the frequency range used for analyses into equally-spaced intervals (bins) in a logarithmic scale. Take an average of phase-velocity data in each bin. (ii) Exclude the results from the analyses either when the wavelengths relative to an array radius lie out of the range defined a-priori for each method or when they exceeds the analysis limits having been evaluated by the use of an array with a sensor at the center point. Also, exclude the results when they seem to align in a line passing through the origin.

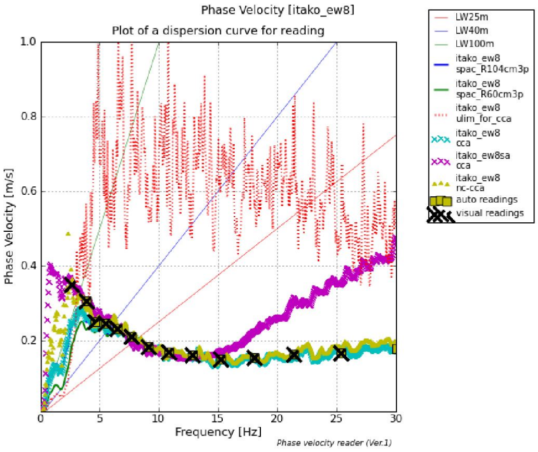
An automatic reading is obtained for each bin by averaging all values left after the procedure (ii). Readings are deleted, however, when they seem to align in a line passing through the origin.

Automatic readings of peak and troughs of an H/V spectrum

First, an H/V spectrum obtained at a single observation point, or an average spectrum if there are multiple spectra as a representative value, is smoothed using a spectral windows having a frequency-dependent window width. Peaks and troughs of the spectrum are searched from the lower side of the frequency range by using the derivatives. We search pairs of a peak and a trough to stabilize the analysis result: A pair is excluded from the reading results when the difference in either frequency or H/V ratio between a peak and trough is smaller than a threshold. Also, a pair is excluded when a peak (trough) value is smaller than that of an anterior peak (trough). The peak and trough of each pair, thus obtained, are used for the depth conversion, and the resulting depths are averaged to be the representative depth obtained by an automatic reading.

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

SSS35-P01 Room:Poster Time:May 2 16:15-17:30



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SSS35-P02 Room:Poster Time:May 2 16:15-17:30

Sophistication of microtremor methods to survey shallow structures, Part2 : Application of automatic reading algorithms

SENNA, Shigeki[1*] ; CHO, Ikuo[2] ; FUJIWARA, Hiroyuki[1]

[1]NIED, [2]AIST

We have been seeking an efficient way to maximize the potential of the microtremor methods for shallow surveys. It is considered that a practical approach has been gained in the observation by the development of portable seismometers (Senna, 2006, 2012) and by the finding of the full usability of the data obtainable by a miniature array (radius less than 1m), optionally together with a small irregular-shaped array (radius less than 10 m) consisting of three seismometers (Cho et al., 2013a).

As an efficient way to infer an S-wave velocity structure, we consider that a classical, simple profiling method (SPM), where a dispersion curve is directly converted into an S-wave velocity structure (e.g., Heukelom and Foster, 1960), is a good scheme from a view point of simplicity, thus, the balance between the efforts and the information to be extracted. It is true, however, that we frequently like to increase to resolution. Facing this dilemma, we suggested a simple tool 'H/V depth conversion' (Cho et al., 2013). We found that the use of an H/V depth conversion followed by a simplified inversion method (SIM) of Pelekis and Athanasopoulos (2011) can in fact increase the resolutions (e.g., Senna et al., 2013; Yoshida et al., 2013).

The current challenge is to further promote the efficiency in the data processing procedure. A visual reading of analysis results, which we take at the current time, is time consuming to deal with a vast mount of microtremor data, now obtainable by a streamlined observational procedure. The reproducibility and biases depending on analyst constitute other kinds of problem of visual reading.

To address this problem, Cho et al. (2014, thismeeting) invented automatic-reading algorithms. In this study we test their algorithm by applying it to observed data to compare the results with those obtained with visual readings. Our method of observation and analysis is described in the following.

1. Observation

Observation duration is set to 15 minutes irrespective of the array shape, where either miniature arrays with a radius of 60 cm or irregular-shaped arrays with radii about 3 to 10 m are used.

2. Automatic analyses and readings of phase velocities and H/V spectra

The selectin of the data portions and the spectral analysis are automatically executed by using the software BIDO. Cho et al. (2014)'s algorithms are used for automatic readings of phase velocities and H/V spectra.

3. Inferring 1D S-wave velocity structures and constructing 2D sections

A dispersion diagram, represented by the relation between the wavelength, L, and phase velocity, Vr, is converted into a 1D S-wave structure having the relation between the depth, D, and S-wave velocity, Vs, where relations $Vs= Vr/0.92$ and $D=0.375L$ are used (SPM). The resulting 1D structures are spatially interpolated to obtain a 2D section, where H/V depth conversions are overdrawn.

The above procedure from 1 to 3 is fully automatically executed. Incidentally, this study include no examination on SIM because no automatic algorithm has been developed yet because of the robustness problem.

We applied the above procedure to microtermor data obtained along survey lines in four different areas with variable geological environments (e.g., Itako City, Hadano City, Kashiwa City, Urayasu City). As the results, natural views of 2D S-wave velocity sections are obtained in all cases, similar to those obtained by visual readings. Furthermore, resulting velocity sections are consistent with other kinds of subsurface structural data (i.e., geological sections, N-value distributions, the 3D soil model of Senna et al. (2013)). We consider that, needing further improvement, Cho et al. (2014)'s algorithms can provide us with acceptable results at the first stage of automating the analysis procedure.

Keywords: Microtremor, velocity structure, surface waves, phase velocity, array, underground structure model

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SSS35-P03 Room:Poster Time:May 2 16:15-17:30

Future Initiatives of development of microtremor survey observation system

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The microtremor observation has treated till today as physical investigation information, including the structure model creation for strong motion prediction of the researcher and engineer , etc.

If microtremor observation can observe easily and the observed data can be easily transmitted to a database with information on that observation point, it can expect that the number of collection of observational data will increase explosively in the future because an amateur can also observe, and the advancement of structural model and prediction of seismic strong motions will be attained by leaps and bounds.

It will become an unprecedented thing which leads to grasp of detailed damage distribution, and the improvement in accuracy of real-time earthquake information from the above.

Keywords: microtremor, survey observation system, cloud system, big data

SSS35-P04 Room:Poster Time:May 2 16:15-17:30

Estimation of phase velocity of Rayleigh wave using linear array

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Since the spatial autocorrelation (SPAC) method has been proposed by Aki (1957), the observation using a circular array of evenly spaced sensors and a central sensor becomes a commonly used measurement technique in the microtremor survey method (Okada, 2003). However, in practice, the strict arrangement of sensors required by the method is difficult to conduct because of the limit of real environment. In order to slacken the requirement of the arrangement, Chavez-Garcia et al. (2005) discussed the validity of performing the SPAC method with a linear array. However, the conclusion of this research is result-based and is not backed by theoretical demonstration. Aki's autocorrelation coefficient could be alternatively seen as the azimuthal average of CCFs (Okada, 2003; Shiraishi 2006). A CCF consists of the Bessel function and an error term which varies with the azimuth of sources. By taking the azimuthal average, the error term vanishes and direct J_0(kr) can be obtained. The discrete formula of the CCF offers the possibility of extending the original SPAC method. In this research, we develop the solution by controling the error term in CCF which can obtain directly the phase velocity instead of using records of sensors in a line instead of azimuthally arranged ones.

Under the assumption: 1) Only the fundamental mode is dominated. 2) Different sources are not correlated, the real part of discrete formula of CCF could be expressed as (Shiraishi, 2006). If we neglect the terms of order larger than 6, we can obtain:

Re(γ_{pq}=J_0(kr)-2J_2(kr)$\sum\lambda_l$cos2θ_l+2J_4(kr)$\sum\lambda_l$cos4θ_l. It can be seen that there are only three unknown variables kr, $\sum\lambda_l$cos2θ_l and $\sum\lambda_l$cos4θ_l. It is required of at least three sensors (3 different intervals) to solve the 3 unknown variables theoretically. The three sites need to be in a line to make the three CCFs share the same unknowns. Because of the coupling variables and non linear functions, we use the genetic algorithm and particle filter to solve out the optimum solution.

In order to comfirm the validity of this new theory preliminarily, the simple wavefield composed of unidirectional plane wave is used to examine the accuracy of estimating phase velocity obtained from a linear array with 3 sensors. The distances between adjacent sensors (r and 0.5r, r=30m) are set to be different so that we can have totally 3 different CCFs to solve out the optimum solution. Except for the analytical simulation, we also applied a field test to examine the availability of the new method. We have applied field test to comfirm the availability of the method. Observation was conducted on 23 October 2013 at the parking lot of Zoorasia Yokohama Zoological Gardens (ZRS) in Yokohama city of Japan. We deployed 7 seismometers (KVS-300, moving speedometer) constituting two linear arrays. The two linear arrays forms an angle of 60 degree so that the SPAC method could be applied for confirmation.

In the analytical simulation, we confirmed the availability of the new method. The sensitivity of CCF with respect to phase velocity depends on the direction of linear array. When the sensitivity is low, the estimation will be bad. Hence, it is better to use at least two linear arrays forming an angle (90 degree is the best). In the field test in Yokohama, we applied both the SPAC method and the new method using 7 speedometers. Both SPAC method and the new method show good match with the theoretical dispersion curve. The new method shows narrower effective scope and shows some unstablity in both low and high frequency range. Through both simulation and field test, the availability of the new method has been confirmed. This new method makes the arrangement of sensors easier which needs only two linear arrays with a non-strict angle. In the future, we will study more about improving the inversion technique and the application of linear array.

Keywords: SPAC method, linear array, coherence complex function, particle filter

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Estimation of Subsurface Structure using Microtremor Observation in Ogasawara Iwo-To Island

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Ogasawara Iwo-To island is an active volcanic island which is located on the southernmost part of Izu-Ogasawara arc. The microtermor obserbation was carried out during the period from December 18 to 21, 2013 in Ogasawara Iwo-To island. The microtremor measurements were performed at 54 sites as 3-component seismometers for horizontal-to-vertical spectral ratio (HVSR) analysis. The obtained HVSRs of microtremor are used to determine the dominant frequencies of vibration of the subsurface structures beneath several recording sites in Ogasawara Iwo-To island. The H/V peak period varies from 1.1 to 3.5 sec.

For using the SPAC method of microtremor, the circular-array microtremor data were recorded by 6 seismometers distributed along the circumferences of two circles as well as a seismometer deployed in the center at two sites in the center of the island. The phase velocities and the S-wave velocities of the subsurface structures down to a depth of several km were estimated at each site from the microtremor data by using the SPAC method.

Keywords: microtremor, Ogasawara Iwo-To Island, subsurface structure

SSS35-P06 Room:Poster Time:May 2 16:15-17:30

Determination of Subsurface Structure of the Mt. Daisen area in Tottori Prefecture by Microtremor and Gravity Survey

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Earthquake damages occurred by the earthquake that occurred at the Middle West of Tottori in 1983 , 2002 and the 2000 Western Tottori earthquake in Mt.Daisen area of Tottori Prefecture. It is supposed that the damage influenced the subsurface structure. It is important that the information of subsurface structures is obtained for prediction of ground motion in the area. Microtremor and gravity surveys were carried out in the plains of the shore part and Mt.Daisen area. S-wave velocity models are obtained at the array observation 3 sites and predominant period distribution at 3-components observation newly. The gravity anomalies were obtained by gravity survey data newly.

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Estimation of inter-station Green's functions using microtremor array data

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The seismic interferometry technique is used to evaluate seismic velocity structure beneath two observation sites [e.g., Ma et al. (2008); Yamanaka et al. (2010); Asano et al. (2012); Hayashida et al. (2014)]. The technique can be applied under the assumptions of non-stationary and uniform distribution of microtremor (ambient noise) sources and it is important to investigate whether the data satisfy the conditions. The array observations of microtremor [Yoshimi et al. (2012)] were conducted at 13 sites in Niigata prefecture, Japan. The surveys were carried out for more than 10 days per site and each array consists of three equilateral triangular arrays whose radii range from several hundred meters to several kilometers. Here we used the data to estimate inter-station Green's functions with the seismic interferometry technique. The stacked cross-correlation functions (CCFs) of microtremor showed coherent and dispersive wave trains in frequency ranges between 0.4 and 1.0 Hz for the small array, 0.2 and 0.7 Hz for the middle array and 0.1 and 0.6 Hz for the large array. The wave trains derived for each array correspond well to each other regardless of azimuth angles, showing the effect from the abnormal microtremor source can be negligible in this study. We also calculated theoretical Green's functions from the estimated S wave velocity structures with the spatial autocorrelation (SPAC) method for each site, assuming 1D velocity structure. The agreements between the calculated Green's functions and the derived CCFs from the seismic interferometry are generally good, especially at lower frequencies. Our results suggest that a combination of velocity structure estimation with surface-wave phase velocity (conventional array methods) and velocity structure validation with Green's function (seismic interferometry technique) provides better estimations for S wave velocity structures.

Acknowledgements:
We used the microtremor array data observed in a research project funded and supported by Japan Nuclear Energy Safety Organization (JNES).

Keywords: microtremor, seismic interferometry, Green's function, group velocity, SPAC method

SSS35-P08 Room:Poster Time:May 2 16:15-17:30

Seismic basement structure estimated from seismic interferometry and microtremor analysis

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Recently, seismic interferometry has been considered to be a powerful tool for subsurface structure survey. Seismic interferometry is a method that produces pseudo reflected waveform data by computing the autocorrelation function (ACF) of seismic waveform record. In this study, we estimate the seismic basement structure beneath the northwestern Noto Peninsula from seismic interferometry and microtremor analysis. We examine the reliability of seismic interferometry and microtremor analysis by comparing those results with the results from gravity anomalies and a reflection seismic survey (Sato et al., 2007) in this area.

For seismic interferometry, we use waveform data of the aftershocks of the 2007 Noto Hanto earthquake at 44 seismic stations which are located in the northwestern Noto Peninsula. We apply high-pass filter of 2 Hz to SH component of displacement waveform and set a time window of 10 s after the arrival of S wave to calculate ACF. We make the average ACF by stacking all ACFs at each station. For microtremor analysis, we performed microtremors observation at 44 points where the stations for the aftershock observation were located and calculate H/V spectrum at each station. We estimate the basement structure in the analyzed area by assuming two-layer structure from ACF and H/V spectrum.

For the ACF analysis, it is difficult to identify the dominant peak of ACF for most stations. Especially, we cannot estimate the basement depths where the basement depths estimated from the reflection seismic survey (Sato et al., 2007) are shallower than 100 m. Finally, we obtain the basement depths at 14 of 44 stations. On the other hand, for the microtremor analysis, we can estimate the basement depths at 35 of 44 points. This indicates that the seismic interferometry with ACF is not an effective approach to estimate the basement depths in the northwestern Noto Peninsula.

We compare the basement depths estimated from ACF, H/V spectrum and gravity anomaly each other. These estimates are approximately coincident each other and shows that the basement depth of the Kuwatsuka block is shallower than that of the Saruyama block. Coseismic uplift was observed in the Kuwatsuka block at the 2007 Noto Hanto earthquake. Therefore, the results of this study is coincident with the hypothesis that the activity of active faults on seafloor near the coast causes the uplift of the Kuwatsuka block and makes its basement depth shallower (Hiramatsu et al., 2008).

Acknowledgements: We are grateful to the group for the joint aftershock observations of the 2007 Noto Hanto Earthquake for the use of waveform data and to NIED for the use of the instrument of microtremor observation. We thank Dr. Shigeki Senna for helpful advice.

Keywords: auto correlation function, H/V spectrum, gravity anomaly, geological block structure, the Noto Peninsula

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Retrieval of Green's function in a 3D inhomogeneous medium with nonisotropic source distribution using interferometry

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Seismic interferometry is known to retrieve Green's functions in an elastic homogeneous medium with isotropic source distribution (e.g., Wapenaar and Fokkema, 2006), and is applied to estimate velocity structures using long time series of ambient noises (e.g., Shapiro and Campillo, 2004). However, the realistic noise field might be an inelastic inhomogeneous medium with nonisotropic source distribution, and thus the reliability of retrieval of Green's functions using seismic interferometry should be examined.

We study on the reliability of seismic interferometry in a 3D inhomogeneous structure model of Kanto basin with nonisotropic source distribution. The numerical study on seismic interferometry was conducted by using 3D FDM. We cross correlated the surface responses at two sites with multiple surface sources. We used Yamanaka and Yamana (2006) for the 3D inhomogeneous model of Kanto basin. Nonisotropic source distribution was made by using sources located only on the sea area. We investigated the influence for the cross correlation functions by comparing with that in a homogeneous medium or isotropic source distribution.

In a case of homogeneous medium with isotropic source distribution, we see slight difference between the cross correlation function and Green's functions, but the surface wave component was well retrieved and surface wave velocity compares well with the Green's function. The slight difference might have been caused by the approximations in seismic interferometry (e.g., Kimman and Trampert, 2010). The cross correlation function showed symmetry for positive and negative lagtimes. In a case of homogeneous with nonisotropic source distribution, the cross correlation function shows asymmetry whose surface wave cannot be seen in positive lagtimes. However, the cross correlation functions in negative lagtime compares well with that retrieved with isotropic source distribution, and it showed good agreement in terms of group velocity. These indicate the influence of source distribution on seismic interferometry would be large as indicated in numerous studies (e.g., Tsai, 2010).

In a case of a 3D inhomogeneous model of Kanto basin, the cross correlation function showed asymmetry even with isotropic source distribution. That is, an inhomogeneity complicates wave propagations and then make apparent source distribution nonisotropic even with the isotropic case. Specifically, larger amplitudes in negative lagtimes than that in positive lagtimes indicate that eastern sources became large apparently. Considering the Kanto basin model, Kanto mountains located in western part and Pacific Ocean located in eastern part, where have thick sediment layers, the eastern sources would have excited surface wave significantly, which caused apparent nonisotropic source distribution. Due to asymmetry in the cross correlation function, it does not match with the Green's function. Group velocities also show asymmetry, however, they agrees to that of Green's function. In a case of a 3D inhomogeneous model with nonisotropic source distribution, the cross correlation function shows asymmetry and show less agreement with the Green's function. However, the group velocity shows agreement.

As a result, the retrieval of Green's function using seismic interferometry is strongly influenced by source distributions. Moreover, an inhomogeneity affect to source distribution, it would also be the problem. In a realistic case, therefore, to understand how much isotropy is satisfied is important. Because understanding the source isotropy is tough, it is important to examine the influence considering with realistic applications. However, on group velocity estimations as many applications, the reliability showed good in this study, suggesting the high possibility for reliable applications in seismic interferometry.

Keywords: Seismic interferometry, Green's function, inhomogeneous, isotropic source, 3D FDM

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Estimation of subsurface structure by high density microtremor observations in Kochi Plain

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Kochi Plain is located around source region of the great Nankai Earthquake. Strong ground motion is expected in this area, because soft subsoil is widely deposited in Kochi Plain. In this study, we investigate H/V spectra of microtremor in the Kochi Plain. Microtremor study with single station is cheaper, quick and easier way than sampling boring core. It is convenient to reveal horizontal variation of soil/basement structure. We append 213 measurements in addition to previous reported 1041 measurements (Oishi et al., JpGU 2013, SSS35-P02). In total 1254 measurements are used to H/V spectral analysis. Figure shows distribution map of dominant periods by H/V spectral analysis based on microtremor observations in Kochi Plain. In perspective, dominant periods of H/V spectra around northern Urado-Bay region are longer than other regions. According to soil/basement model using boring data, the bedrock depth at this region is especially deep but boring which reaches the bedrock is limited. In contrast, H/V spectral analysis is useful to grasp the extent of region with deep soil/basement boundary. Dominant periods of H/V spectra around western part of Kochi Plain are relatively shorter than Urado region. The damaged areas of the past 2 (1854 and 1946) Nankai Earthquakes match with areas where the dominant period is long and/or the amplification factor is large. High density observations in this region show clear local variations. These are not reflected on current hazard maps or seismic intensity estimation maps. Using H/V spectral analysis based on high density microtremor observation, we are detecting patterns of soil/basement structure which has not be grasped using only boring core data.

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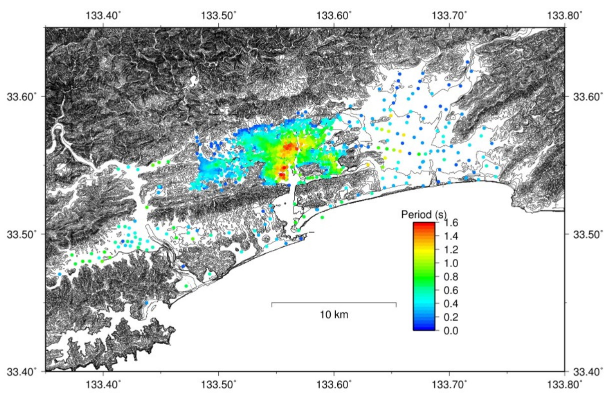
Keywords: microtremor, H/V spectral ratio, subsurface structure, Kochi Plain



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Recent Geological Interpretation of A Liquefied Area: A Case Study in Urayasu City, Japan (1)

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At Urayasu High School (Urayasu City, Chiba Prefecture), where one of authors worked, the 2011 Great East Japan Earthquake caused the formation of two large open cracks from which large amounts of sand and water erupted as a result of soil liquefaction (Kusunoki et al., 2011). The objectives of this study were to investigate both the cause and the mechanism of this phenomenon. The site is located on reclaimed land, and a survey of the site's subsurface geology was carried out by hand auger boring and simple dynamic cone penetration testing to observe the stratigraphy of the reclaimed bed. Aerial photographs of the different stages of the reclamation were also used for analysis.

The survey area was the school grounds, which are located several hundred meters from the former seashore. Holocene deposits were situated at a depth of approximately 3-4 m. Two large open cracks formed in the ground: crack '1' in the NNE-SSW direction and crack '2' in the WNW-ESE direction. Beneath the cracks, we found row of piles from the original ground reclamation work. These rows of piles had been laid underground, and the reclaimed bed consisted of sand and silt. The cracks appeared to be due to the difference in vibrational characteristics between the opposite sides of each crack. Also, the facies of the reclaimed bed were notably different on the opposite sides of each crack. In the cross section of crack '2', the Nd-value*was very large on the northeast side (Nekozane River side) but relatively smaller on the southwest side. In the cross section of crack '1', the facies of the reclaimed bed from approximately 2 m above to the top of the Holocene deposits were sandy on the western side relatively large Nd-value, but on eastern side mainly formed of silty material recorded almost 0.

Analysis was conducted using aerial photographs and revealed that both cracks '1' and crack '2' were located on the same discontinuity in the reclamation work history, both spatially and temporally. Therefore, the survey area contained three sections of reclaimed land demarcated by the two cracks. Moreover, a fourth section consisted of Holocene deposits. Chronologically, the survey area contained (a) 'Kaimenka-tochi' **(Urayasu City, 1985), (b) reclaimed land composed of sand and silt dredged from the seabed, and (c) the surrounding embankment. The reclamation process differed between areas (a) and (b). Area (b) was the widest and was typical of reclaimed land. Area (c), in contrast, was not constructed by dredging sand and silt from the seabed. Crack '1' was located between areas (b) and (c), and crack '2' was located between areas (a) and (b).

Therefore, the occurrence of these cracks seems attributable to discontinuities in the reclamation history. This case shows that recognizing the geological and historical processes of both the Holocene deposits and the reclaimed land is an important aspect of disaster prevention.

*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.

**'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.

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Keywords: liquefaction, crack, dynamic cone penetration test, Urayasu, reclaimed land