Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-01 Room:102A Time:May 27 14:15-14:30

Numerical interpretation of anchoring mechanism by using Bonded Particles Model

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In order to clarify the anchoring mechanism of ground anchor and develop the effective design method, it is convinient to build the numerical model that can well reproduce the mechanical behavior and represent the fracturing process around the anchor part under various specific conditions. The mechanical behaviors of ground anchor are simulated by distinct element methoed using bonded particle model. As the result of the simulations, the typical mechanical behaviors and the well-known empirical law of ground anchor can be well reproduced.

Keywords: ground anchor, distinct element model, crack initiation and propagation

Japan Geoscience Union Meeting 2015
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STT13-02 Room:102A Time:May 27 14:30-14:45

3D Time-lapse monitoring of water infiltration in the vadose zone by means of a high-speed resistivity measurement tool

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Infiltration process of water into the surficial vadose zone of an embankment was monitored at short intervals by means of a newly developed high-speed resistivity measurement tool. The tool can transmit 24 individual current signals and measure 24 potential responses simultaneously. A code division multiple transmission technique was adopted for the current signal transmission. It took only 30 seconds to obtain and store a dataset composed of a total of 576 (24 by 24) potential data along with time series waveforms. The tool enabled us to conduct high-speed time-lapse or dense 3D resistivity measurements in the field. We monitored infiltration process of surface water into the vadose zone of an actual embankment. A total of 4 current lines and 4 potential lines were set parallel on a flank of the embankment, and infused water into the vadose zone through a narrow and shallow trench dug on the crest. Electrode stakes were placed at 25 cm spacing along each line, and spacing between the lines was set to 50 cm. A total of 6,912 (12 pairs x 576) data were acquired at 5 min intervals in the beginning and at 30 min later. 3D electrical resistivity tomography (ERT) analysis, applied to the dataset composed of a total of 40 stages during the infiltration across two days, successfully imaged the extent of infiltrated water in the vadose zone. Consequently, our field measurements demonstrated the usefulness of dense time-lapse 3D ERT monitoring for the characterization of dynamic unsaturated permeability of the vadose zone of embankments in the field.

Keywords: resistivity, vadose zone, infiltration, time-lapse monitoring, 3D

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-03 Room:102A Time:May 27 14:45-15:00

Reliability of hydraulic conductivity and specific storage structures estimated by Self - potential inversion.

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The objective of this study is evaluation of reliability of estimated hydraulic conductivity and specific storage structure from self-potential (SP) data under the realistic condition. The hydraulic conductivity and specific storage could be estimated from a transient SP inversion with the information of flux data. We have demonstrated that these parameters could be estimated with high resolution numerically in ideal case such that the required data is enough and artificial structure can be negligible. However, such condition is rarely satisfied in many field cases. As one of difficulties, the lack of flux data is assumed. The sampling rate of the measurement of flux data could be too low because of the difficulty of measurement. We adopt the spline interpolation to a sparse sampling data, and evaluate the reliability of estimated image using numerical tests. We calculate the SP signals following to the fluctuated pumping rate. We use the calculated SP signals with same sampling rate as calculation as an input data in the numerical test. The down sampled flux data is assumed to be the measured data in the test. Our numerical test shows that both hydraulic conductivity and specific storage structure can be estimated correctly from the interpolated deficient flux data with the trend almost same as the true variation. When the interpolated deficient flux data does not reconstruct the trend of the true variation, only the hydraulic conductivity structure can be estimated with low resolution while the specific storage could not be estimated at all.

In addition to the lack of flux data, the existences of artificial structures are also the obstacles for the SP inversion in a real field. For example, a high-conductive metallic casing pipe leads the SP signal far from the SP source without decrease of the electrical potential. Therefore, the estimated image ignoring this effect would be biased. We also evaluate this effect by numerical tests. The SP singles affected by the metal casing are used for the inversion test without considering the effect. Both hydraulic conductivity and specific storage near the metal casing in the inversion image are estimated to be a little lower than those of the test model. In addition, the strong artifact appears in the estimated image of specific storage. From these results, we conclude that the estimated image of hydraulic conductivity structure is robust under such unrealistic conditions. For the correct estimation of specific storage structure, the flux data with high quality is necessary.

Keywords: Self potential, Inversion, Hydraulic conductivity, Storage coefficient, Metal casing, Interpolated data

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-04 Room:102A Time:May 27 15:00-15:15

An experiment of subsidence monitoring in the quarry area by a seismic source during two months: near source observation

KAMIMURA, Aya[1*] ; KASAHARA, Junzo[1] ; FUJII, Naoyuki[1] ; USHIYAMA, Motoyuki[1]

[1]Shizuoka Univ.

Introduction

We tested to monitor temporal changes in the subsurface at the quarry area. At this quarry, there is a subsidence warning system to detect micro-earthquakes associated with the subsidence measured by seismometers. At the past subsidence, seismic vibrations were repeatedly observed during several months, but the 2014 subsidence showed only four vibration events preceding to the subsidence. It is thought that if we can observe any other temporal changes of the subsurface before the vibration, we could help to find subsidence. Therefore we carried out ”seismic time-lapse observation”. We used a control seismic source on the ground at fix location, and tested whether any changes of the subsurface changes during the observation period was caught or not.

Field test

We carried out one-week experiments twice in July and August of 2014. The first and the second experiments were from 16 to 21 in July and from 21 to 25 in August, respectively. We used electro-magnetic vibrator developed by Kawasaki Geological Engineering Co. Ltd as the seismic source. We set 100-second sweep from 10 to 50 Hz and 5-second rest with the GPS time accuracy and repeated 32 sweeps with 5 second rest in an hour. We operated the vibrator 12 hours consecutively at night (20:00 - 08:00).

We recorded accelerations signals of reaction-mass and base-plate with desired signals, and seismic waves at east of the source, south of the source, and near the source. Local warning system of 97 geophones also recorded these artificial seismic data.

Analysis

We carried out FFT conversions of observed data. We transformed two sweep sequences of seismic records to the frequency domain and stacked 16 sets of data in 1 hour. We calculated source signature using the reaction-mass and the baseplate accelerations of the vibrator. The transfer functions between the source and a receiver were obtained by the division of observed spectra by source signature. After applied window function in spectral domain, we inverse-transformed the data into a time domain.

Results

In this paper we report the characteristics near the source. When we set the amplitude of seismometer beside the source was 100, that of eastern seismometer (ca. 35m east of source) was 5, and that of southern seismometer (ca. 45m south of source) was 2 (vertical axis). The transfer function of 18 and 19 of July showed a change in comparison with others periods. There were few changes of the transfer functions during an experiment period of August.

Discussion and conclusions

We checked the weather condition during experimental periods. On July 18 03:00-04:00, 28mm/hour rainfalls measured by the neighboring precipitation observatory, and intense thunderstorm was recorded at the test field. In other periods, such heavy rainfalls were not observed. From these data, it is thought that the near surface layers including the water by rainfalls changed the transfer function of the test field.

Acknowledgements

This study was supported by the Center for Integrated Research and Education of Natural Hazard, of Shizuoka University. The field experiments was carried out by Kawasaki Geological Engineering Co., Ltd.

References

Kasahara, J., et al., Real time Imaging of CO2 storage zone by very accurate-stable-long term seismic source, Energy Precedia, 2013d.

Kasahara, J., et al., Observation of very larger temporal changes due to the near surface effects and importance on the time-lapse study, Proc. Soc. #130 Exploration Geophysicists of Japan, 212-215, 2014.

Kubota, R., et al., Development of the Seismic ACROSS using electro-magnetic vibrator, Proc. ”2nd KACST-KCUST-JCCP international workshop on Surface and Subsurface 4D Monitoring”, KAUST Feb. 2014.

Kunitomo, T., et al., Active monitoring of the Earth’s structure by the seismic ACROSS - Transmitting and receiving technologies of the seismic ACROSS, Proc. 1st International Workshop ”Active Monitoring in the Solid Earth Geophysics”, in Mizunami, Japan, S4-04., 2004.

Keywords: time lapse, artificial seismic sourcce, subsidence, seismic method, disaster prevention

Japan Geoscience Union Meeting 2015
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STT13-05 Room:102A Time:May 27 15:15-15:30

Imaging of temporal changes at the surface subsidence area

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Introduction

We have carried out seismic studies to monitor the temporal change of subsurface in CCS, EOR and oil/gas reservoirs. For these studies, we have used ultra-stable seismic source called ACROSS (Accurately Controlled and Routinely Operated Signal System) (Kunitomo and Kumazawa, 2004). Because ACROSS seismic source is usulally installed in heavy concreate block, it is difficult to rellocate from one place to another. Instead, we used a conventional seismic source for this study. We carried out the time lapse experiments at one of quarry sites in Japan.

Method and Field observation

A conventional electro-magnetic seismic source with the modification of ACROSS methodology (Kubota et al., 2014) was used. A set of 100-second sweep from 10 to 50 Hz and 5-second rest with the GPS time accuracy was repeated 32 times in an hour. Seismic data of 97 15-Hz vertical geophones buried at 20 m depth and two 4.5-Hz borehole seismometers at 70 m and 200 m depths were sampled every 1 ms by the GPS time base too.

We repeated two observations in July and August in 2014. The first and the second one were between 16 and 21 in July and between 21 and 26 in August 2014, respectively. The size of the quarry is 2 km x 4.4 km. The experiments were only during the night time from 8 PM to 8 AM.

Analysis

We used similar analysis as the ACROSS processing (Kasahara et al., 2014). Observed data (1 or 12 hours) were stacked. Transfer functions between source and receivers are obtained by division of observed records by source signature calculated by accelerations on reaction mass and base plate. By 210 seconds (two sweeps) data for first stage stacking, we could estimate noise spectra. As the final stage, the residual waveforms of P portion were back-propagated by the method developed by Kasahara et al (2011).

Results

We obtained transfer functions for all datasets. By use of one hour data, we can clearly identify P arrivals up to 1.7 km distance. The transfer functions are quite stable though the seismic source is conventional type because we kept the seismic source at the same condition at the fixed point. However, if we compare the waveforms obtained in December 2013 with ones obtained in July or August 2014, we can notice large changes due to the differences of source installations.

Even within each week in July or August, the residual waveforms show changes just after P first arrivals. The P coda might be changed by temporal change of very shallow layers. By the back-propagation, we obtained the time-lapse image of the changing area. The changing areas are in two directions such as NW and SWW and they seem similar to the previous subsidence zone since 2000.

Acknowledgements

This study was supported by the Center for Integrated Research and Education of Natural Hazard, of Shizuoka University. The field experiments were carried out by Kawasaki Geological Engineering Co. Ltd.

References

Kasahara, J. et al., Imaging of ultra-long term temporal change of reservoir (s) by accurate seismic sources(s) and multi-receivers, in Extended abstract of ”EAGE workshop on Permanent Reservoir Monitoring (PRM)”, 40-44, Feb.-Mar., Trondheim, Norway, 2011.

Kasahara, J. et al., Real time Imaging of CO2 storage zone by very accurate-stable-long term seismic source, Energy Precedia, 2013.

Kasahara, J. et al., Observation of very larger temporal changes due to the near surface effects and importance on the time-lapse study, Proc. Soc. #130 Exploration Geophysicists of Japan, 212-215, 2014.

Kubota, R. et al., Development of the Seismic ACROSS using electro-magnetic vibrator, Proc. ”2nd KACST-KCUST-JCCP international workshop on Surface and Subsurface 4D Monitoring”, KAUST Feb. 2014.

Kunitomo, T., and Kumazawa, M., Active monitoring of the Earth’s structure by the seismic ACROSS - Transmitting and receiving technologies of the seismic ACROSS, Proc. 1st International Workshop ”Active Monitoring in the Solid Earth Geophysics”, in Mizunami, Japan, S4-04., 2004.

Keywords: time lapse, seismic imaging, backpropagation, subsidence, ACROSS, seismic method

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-06 Room:102A Time:May 27 15:30-15:45

The Hydrodynamic effect on silicate scale growth in microscopic flow inferred from numerical simulation.

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Formation of inorganic sparingly-soluble salts, anhydrite and silica from brine is known as a cause of scale in pipeline systems. Scaling is a key phenomenon to understand fluid-flow system in subsurface or sub-seafloor structure, because the scale growth strongly affects the fluid circulation of subsurface or sub-seafloor hydrothermal systems by chocking any flow channel.

Several works (Takeno et al. 1998; Bolton et al., 1999) simulated the subsurface permeability change by the silica precipitation using the deposition rate law formulated on the basis of the simple kinetics (Rimstidt and Barnes, 1980). However it has been reported that the predicted magnitude of the deposition rate is extremely slower than measured values in the laboratories (Malate and O'Sullivan, 1992; Weir and White, 1996). By the way, a high rate growth of scale is often observed where the flow stagnates, so that the inhomogeneous flow could influence the deposition of the silica scale which is an alternative process of scaling. Nevertheless, relatively little research has been undertaken to investigate hydrodynamic effect on silica scaling. The aim of this work is to investigate the kinetic of adhesion of silica particles on the wall surface based on the hydrodynamic effect using the numerical simulation. Although we focus on the elementary (microscopic) process of the adhesion of silica particles, our ultimately goal is to help us to simulate the macroscopic flow in subsurface or sub-seafloor hydrothermal systems based on the hydrodynamic process by the feedback from this study.

We simulate the adhesion of silica particles using the lattice Boltzmann method (LBM) combined with the smoothed-particle method (SPM) (Nakayama and Yamamoto, 2008). This method uses fixed Eulerian grids for the fluid and represents the particles by certain smooth body forces in the Navier-Stokes equations instead of treating the particles as boundary conditions to the fluid. The LBM is adapted to the flow in the complex geometry due to the simple treatment of the boundary condition. The LBM combined with the SPM is the scheme having low computational cost to deal with many particles in a relatively simple manner. We assume that the particle whose velocity reaches the threshold of the convergence is adhered and is fixed on the wall. We use a two-dimensional parallel plate model in which flow rate and wall roughness are varied and derive the constitutive relation between the deposition rate and flow rate and wall roughness.

A high rate of scale growth is found in areas of low flow rate and it is consistent with the observation at the experiment (Garibaldi, 1980). Therefore, we conclude that the hydrodynamic effect on the growth of silica scale is important to understand the hydrothermal circulation.

Keywords: silica scaling, hydrodynamics, particle adhesion, lattice Boltzmann method, smoothed profile method

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-07 Room:102A Time:May 28 11:00-11:15

Determining the three-dimensional position of the anomalous resistivity body in upper oceanic crust using MMR method

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Magnetometric resistivity method (MMR) is one of the controlled source methods, which is useful tool to estimate the electrical resistivity structure in upper oceanic crust. This method consists of a vertical bipole electric current source and OBM (ocean bottom magnetometer) as a receiver. One-dimensional resistivity structures estimated easily from the relation between the source-receiver distance and value of magnetic field induced by the vertical bipole electrical current source, but three-dimensional resistivity structure is hardly estemated. Therefore, we introduce magnetic field anomaly map in order to determine the three-dimensional position of an anomalous resistivity body in the oceanic crust. The magnetic field anomaly is difference between magnetic field induced in the reference resistivity structure (without the anomalous resistivity body) and that with the anomalous resistivity body. A magnetic field anomaly is obtained for a pair of a source and a receiver, and the value of the magnetic field anomaly can be plotted at the source position for the receiver. Magnetic field anomaly map for the receiver can be made by magnetic field anomalies at many different source positions. We calculated the magnetic field anomaly for 10 different models with various parameters (horizontal distance between receiver and the anomalous resistivity body, depth of anomalous resistivity body, and so on) by using 3-D forward modeling. Magnetic field anomaly maps for 10 different models are used to derive two relationships in positions between the magnetic field anomaly and the anomalous resistivity body: 1) The anomalous resistivity body exists under straight line between the peak of magnetic field anomaly and receiver position. 2) The other one is the depth of the anomalous resistivity body can be determined by indicating the depth of anomalous resistivity body has proportional relationship with the horizontal distance between anomalous resistivity body and the peak of magnetic field anomaly. These relationships allow us to determine the three-dimensional position of each anomalous resistivity body through magnetic field anomaly maps for more than two receivers.Our results indicate that magnetic field anomaly map is useful tool to determine the three-dimensional position of the anomalous resistivity body , suggesting that a MMR survey requires many vertical bipole electrical current source transmissions with a few OBM to reveal distribution of anomalous resistivity bodies in upper oceanic crust.

Keywords: resistivity structure, Magnetometric Resistivity method, controlled source method, oceanic crust

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-08 Room:102A Time:May 28 11:15-11:30

Improvement of eddy current testing method for sheet piles on harbor

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The applicability and the feasibility of eddy-current testing method for the detection of wall thinning and surface crack of steel structure have been practically confirmed by field and laboratory experiments. Qualitative analysis of cracks has been empirically understood by analog analysis. There has, however, been a growing demand to quantitatively evaluate the cracks. We tackle this problem by use of time series of induced magnetic field by the cracks.

In the present study, we proposed a new digital analysis process to use the induced magnetic field waveform, and validated the effectiveness of the method using numerical simulations. First, we developed a high-speed electromagnetic simulator using a fictitious wave domain method to reproduce the conventional eddy current testing method for realistic sheet-piles seawater model. Then, we confirmed the features of the induced magnetic field waveforms by many types of cracks.

Paying attention to the residuals of the induced magnetic field waveform, we developed a novel migration procedure that has not been used up to now in electromagnetic field. Using this, we could get crack imaging without phase lag. For the evaluation of the crack position and wall thinning of the sheet piles, we also applied attribute analysis used in the field of seismic survey.

Through the application of the digital signal processing using induced magnetic field waveform, we could be successful with developing a high degree of accuracy of the eddy current testing method.

Keywords: NDT, Eddy current testing method, Fictitious wave domain method, Migration, Attribute analysis, Electromagnetic

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-09 Room:102A Time:May 28 11:30-11:45

Applicability of Phased Array Antenna to Ground Penetrating Radar

KIKUCHI, Kaito[1*] ; MIKADA, Hitoshi[1] ; GOTO, Tada-nori[1] ; TAKEKAWA, Junichi[1]

[1]Graduate School of Engineering, Kyoto University

Ground Penetrating Radar (GPR) has been widely used to detect objects in shallow subsurface. A bow-tie antenna, which is one of the major antennas, provides the clear cross sections in the shallow subsurface, especially under the survey line. On the other hand, the resolution across the survey lines depends on its interval. To overcome this problem, we tried to apply a phased array system to GPR. We conducted numerical simulations using a three-dimensional model composed of water, dry sand and some small perfect conductors with cubic shape. We compared two different kinds of antenna, a dipole antenna and a phased array antenna. The phased array antenna has an 8 x 8 sending unit and one receiving unit at the center of the radar. Both antennas have the length of about 0.5 meters. Our results show that the phased array antenna enhanced the noise-to-signal ratio and it also enhanced the amplitude of a scattered wave from a perfect conductor located out of the survey line. We conclude that the application of the phased array system to GPR has a potential to survey with wider angle than the conventional GPR system.

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-10 Room:102A Time:May 28 11:45-12:00

Development of a novel backpropagation technique for waves traveling with diffusive process

SAITO, Takuya[1*] ; MIKADA, Hitoshi[1]

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In the field of geophysics, several electromagnetic processes using waveforms, such as the full waveform inversion technique or the migration procedure, have been applied to visualize the subsurface structure.

While this process is very powerful and effective to interpret the subsurface structure, there are some difficulties in this process when the phase velocity takes complex value, i.e., the propagation of waves includes diffusive process. One method to avoid the instability due to the divergence of energy in the back propagation is to use the reciprocity to propagate from the locations of receivers to every imaging point. However, although this method to exploit the reciprocity theorem is a powerful scheme, amplitude attenuation and phase delay affects could be doubled due to the application of two-way forward propagation procedure in the imaging. In the conventional waveform inversion analysis, the result involves phase delay concomitantly during the back propagate process.

Our novel electromagnetic migration process could overcome this problem. Unlike conventional back propagate process, we invert the time of the residual waveform using forward propagation of this waveform. Then, we summed the resulting waveform without phase delay. Although the amplitude would takes place, it is pretty important to recover the phase delay caused by the forward propagation from imaging points to receivers.

We applied this migration process for the improvement of the eddy current testing method that is one of the non-destructive inspection techniques and confirmed this migration works well.

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-11 Room:102A Time:May 28 12:00-12:15

Seismic wavefield distortion due to anisotropic anomalies near surface

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Reservoir rocks and near surface materials are estimated to be strongly anisotropic for elastic wave propagation (e.g., Sone, 2012). Therefore, it is important to take anisotropy properties into account for estimating accurate geological structure using seismic exploration methods. There are many previous studies of elastic anisotropy, for example, azimuthal anisotropy of qP- and qSV-wave, S-wave splitting, etc. Most of these studies are based on the assumption that media is ”weakly” anisotropic (Thomsen, 1986). When the anisotropy of media is not ”weak”, the assumption may not be applicable. However, the effect of ”strong” anisotropy on the behavior of seismic wave propagation is still not well understood. In this study, we investigate the influence of strong anisotropy on received seismic waveforms using three-dimensional numerical models, and verified capability of detecting subsurface anisotropy. We assumed one model that contains a block of horizontally stratified isotropic layers (transversal isotropy with vertical axis of symmetry), while the other contains an isotropic inhomogeneity sharing the same block. We took the difference in the received waveforms of two models to see how the anisotropy of the medium influences the wavefield based on the orbital analysis of particle motion of the residual wavefield. Our results show that there are meaningful changes in the received waveform mainly due to P-wave and converted-wave (P-to-S) that might be generated by the anisotropy of the materials as secondary seismic sources. Since the anisotropy of the material behaves as secondary sources for incoming seismic waves, we concluded that seismic exploration method is applicable to estimate the anisotropic properties.

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-12 Room:102A Time:May 28 12:15-12:30

Estimation of S-wave anisotropy in the Nankai Trough using active and passive seismic dataset observed by DONET

KIMURA, Toshinori[1*] ; ARAKI, Eiichiro[1] ; MIKADA, Hitoshi[2] ; KODAIRA, Shuichi[1] ; MIURA, Seiichi[1] ; TAKAHASHI, Narumi[1] ; TAKAESU, Morifumi[1] ; NAKANO, Masaru[1] ; MACHIDA, Yuya[1]

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In The Nankai Trough seismogenic zone, which is formed by the subducting Philippine Sea plate beneath the Eurasian plate with rate of 4-6 cm/year, mega-thrust earthquake occurred repeatedly every 100-150 years. In this area, cabled real-time observation system, DONET (Dense Oceanfloor Network Systems for Earthquakes and Tsunamis) and IODP C0002G borehole observatory, have been operated to monitor seismic activity, crustal deformation and tsunami propagation since August 2011 and January 2013, respectively.

For elucidating preparation and generation process of mega-thrust earthquake, which occurs repeatedly in subduction zones, it is important to observe and monitor the stress state, a key parameter governing its fault dynamics in the vicinity of seismogenic fault. In-situ stress analysis such as borehole breakout analysis may provide the orientation and the order of differential stress around the borehole, but it is still challenging to drill seismogenic fault, and is even more difficult to monitor temporal change of stress state, especially in wide area. Therefore, we have to consider another method to estimate stress state. In this study, we performed active and passive seismic data processing to obtain seismic anisotropy using dataset acquired by three-component seismometers installed in the DONET and IODP C0002G observatories. Seismic anisotropy can be a proxy of stress state, and by observing its temporal change is expected to identify change of stress around the seismogenic fault.

As active seismic dataset, we used airgun records observed by DONET and IODP C0002G seismometers during KR13-17 cruise conducted on November 2013. In this study, we used airgun records of eight circular shooting lines around these seismometers with radius of 3 km. In radial and transverse components computed from original horizontal records acquired by these circular shooting lines, P-S converted waves from bottom of shallow sediment were clearly visible. Fast symmetry axis of S-wave was estimated by fitting simple sine curve to amplitude fluctuation with shot-receiver azimuth in radial component, and then we obtained S-wave anisotropy in shallow sediment in the Nankai Trough wide area.

As passive data processing, we apply seismic interferometry method to ambient noise records acquired by horizontal components of each DONET and IODP C0002G seismometer. We computed zero offset 4-C ACF and CCFs (Auto-correlation function and Cross-correlation function) comprising V11, V12, V21, and V22 from ambient noise record observed by horizontal i- and j-direction components. Vij represents impulse response which has i-direction source and j-direction receiver of each seismometer. In the ACF and CCFs calculate from long-term records for two years, several coherent events are visible. These events may be reflected S-wave from each layer, and S-wave splitting affected by seismic anisotropy. We then applied the Alford rotation and layer stripping method to the obtained 4-C ACF and CCFs. Then S-wave anisotropy direction and amplitude beneath each seismometer in each layer above the plate boundary were obtained.

We finally compared the obtained S-wave anisotropy from the active and passive methods. There are some differences between the obtained results from these methods. It may result from some reasons. Airgun records have been affected by 3-D structure around the observatory including seafloor topography and effect of undergoing P-wave anisotropy. Results from passive ambient noise components also have causes of error. The obtained 4-C ACF and CCFs might be contaminated by surface wave component. We now evaluate above mentioned effects to obtained results. Also, we intend to obtain S-wave anisotropy in deeper part from active airgun dataset using weak converted waves from deeper boundaries. We now plan to conduct next airgun survey in March 2015 by R/V Kairei with same settings as KR13-17 cruise to detect temporal change of S-wave anisotropy.

Keywords: S-wave anistropy, Nankai Trough, DONET

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-13 Room:102A Time:May 28 12:30-12:45

Effect of local heterogeneous conditions on growth curves of P-wave

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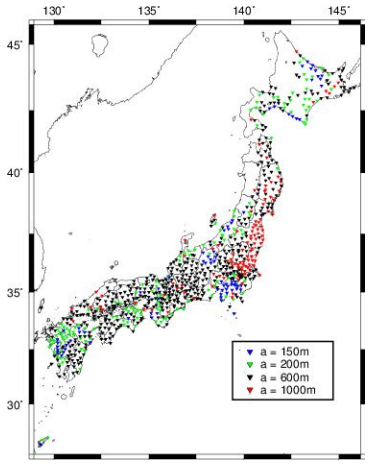
In the Earthquake Early Waning (EEW) system, magnitude and epicentral location of an earthquake are estimated within several seconds after P-wave arrival. According to the Odaka (2003), the equation Bt∗exp(-At) is fitted to the early portion of P-waves. In the equation, A and B are constants and t represented time. From the B value, epicentral distances are estimated using an empirical relationship. The B value decreases as the epicentral distance increases due to the geometrical spreading of seismic waves. As the amplitude of P-waves decrease by travelling through the medium, the gradient of the early portion of P-waves also decrease. So that, the B value of a given epicentral distance marks the specific value and the epicentral distance can be obtained from the B value. However in practice, the B values of different earthquakes having the same epicentral distance show quiet different values. The gap in the B values is sometimes by several hundred times. One of the causes giving major effect on the B value is seismic attenuation due to heterogeneities in subsurface. Seismic waves propagating in heterogeneous medium attenuate due to seismic scattering and absorption. Tsukada et al. (2004) conducted a theoretical calculation on broadening of scalar wave envelopes based on three-dimensional von Karman type random medium. They found that the gap in the B values of different earthquakes having the same epicentral distance is accountable by difference in the scattering condition.

In this study, we theoretically calculate P waves in heterogeneous medium considering the conversion waves between P and S waves, which were ignored in the preceding studies while they give major effect on P-wave envelopes. We show that variation in condition of heterogeneities (in concrete correlation distance) changes the B value. In other word, regional conditions of heterogeneities make the different B values of a given epicentral distance. Then we compare the theoretically calculated B value with one calculated from earthquakes in 1996 - 2011 observed by the K-, KiK-net in Japan. We calculate a regional parameter of heterogeneities (correlation distance) in Japan which can account the fluctuation in the observed B values. As a result, it is found that the spatial distribution of the correlation distance (Figure 1) shows similar tendency with that of a parameter reflecting local heterogeneities, like coda-Q.

In this study we hypothesize that variation in the condition of heterogeneities makes the B value fluctuate significantly and verify it. If we treat the fluctuation in the B values by considering the local condition of heterogeneities, estimation on epicentral distances becomes more accurate. It will improve accuracy of the EEW. Furthermore, B values, that is, initial curve of P-waves can be an exploration tool for local heterogeneities. The early portion of P-wave has a strong advantage that the Born approximation can be used. Complex heterogeneities can be treated by the simple equation.

Keywords: heterogeneities, Born approximation, EEW, scattering, growth curve of P-wave, B-delta method



Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-14 Room:102A Time:May 28 14:15-14:30

Development of hydraulic low frequency marine seismic vibrator

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A towed marine seismic vibrator using hydraulic servo system has been developed. We have fabricated a mock-up source with a slightly, say 60-70 %, scaled size to the real design and conducted several evaluation tests in the sea. The vibrator was towed approximately at a depth of 250m in water. The performance such as maximum sound level, frequency characteristic, horizontal directivity, and vertical directivity of the sound field generated from the source mock-up was examined as a field experiment. The sound source level and the frequency characteristic were equal to or higher than the estimated specification between 3Hz and 300Hz. The comparizon of horizontal with the vertical intensity of the generated sound fields indicate that the generated sound field could be regarded nearly omnidirectional. Seismic survey trial using a short streamer was also conducted following the source characteristic examination. A shot gather was acquired by several emission patterns with different frequency bands in the trial. The results showed the performance of the mock-up to be usable as seismic source in shallow water as a vibrator source that uses mechanical oscillation structure.

Keywords: seismic, vibrator, hydraulic

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STT13-15 Room:102A Time:May 28 14:30-14:45

Study of the exploration focused on shear waves generated by a dipole source

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For the exploration and the development of the hydrocarbon fluid resources such as oil, natural gas, etc., a 3D seismic exploration method has been applied to investigate subsurface structures. In particular, the utilization of airguns and multiple streamers have made use of 3D surveys in practice in the marine environment. Marine seismic sources are in general explosive or impulsive so that the compressional and its mode converted waves have been used in the exploration. For further effective exploitation of the resources, such as enhanced oil recovery, it is necessary to apply much higher exploration technologies. Shear waves are also a candidate to be utilized to investigate physical properties of subsurface materials. Therefore, shear waves have been of interest in research in recent years, but, unfortunately, are known as difficult to be acquired in the marine environment due to water layer in which no shear wave travels through. The generation of shear waves without touching the seafloor is also thought impossible in water. For efficient surveys using shear waves, we need to find an alternative way to generate shear waves.

In this paper, a feasibility study of the exploration focused on the generation of the shear wave is conducted using a dipole source that has been used to generate shear waves in geophysical logging. We first made a scaled model of a deep-tow seismic survey using solid material with a set of reflectors and an overlain water layer. Two dilatational sources with the opposite phase to each other are simultaneously excited to form a point force in the water parallel to solid-water interface. The sound field generated by the dipole in water creates a stress field tangential to the solid-water interface so that the shear wave is generated in the solid. For the model, we performed both acoustic experiment and numerical simulations to see both compressional and shear reflection profiles. Although the signal-to-noise ratio of the acoustic experiment is not sufficiently high, we confirmed that shear reflection profile could be produced. It should be noted that shear waves could be produced in water using multipolar sources fired close to the seafloor, and that some improvements to increase shear wave energy more than the compressional wave need to be pursued for practical use of multipolar sources.

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-16 Room:102A Time:May 28 14:45-15:00

Optimal correction of data from misoriented multi-component geophysical sensors

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One of the most important problems affecting geophysical data acquisition procedures is related to the misorientation of multi-component sensors with respect to a common reference system. Misoriented sensors affect data analysis procedures, which can lead to errors in results and interpretations. These problems generally occur in applications in which the orientation of the sensor cannot be actively controlled and is not known a priori. Common examples are geophysical sensors deployed in borehole installations or on the seafloor. In this presentation we introduce two methods to optimally correct data sets from misaligned sensors.

Firstly, we consider two-component time-series data. These commonly result from the assumption that the vertical axis of a three-component sensor is correctly determined, and therefore the data from that respective component can be excluded from the correction process. This is a common approach and it is used in many applications. We show that the optimal misalignment-correction for such a two-component data set can be estimated in a single, non-iterative calculation step (c.f. Grigoli et al., 2012). The result is optimal with respect to the l_2 norm of the overall deviation between the re-oriented and the optimal data. We demonstrate the functionality of our method by applying it to synthetic and real data examples (seismic data; Vertical seismic profile, Ocean bottom seismometers, Seismological array).

Although the simplification of neglecting the third sensor component is commonly applied, and the resulting deviations are assumed to be negligible, it is still beneficial to take the full information contained in the data sets into account. Therefore, we have developed a reorientation algorithm for multi-component geophysical sensors (i.e. two- and three-component sensors). In the second part of this presentation, we introduce this quaternion-based method, which yields an analytical solution for the (relative) reorientation of sensors in three dimensions. We show that our method is not only fully functional, but also that it is superior to the commonly applied approach of a grid search over the parameter space for finding optimal rotation paramters (c.f. Krieger & Grigoli, 2015). We also demonstrate that the assumption a potential deviation of the vertical sensor component from the true vertical only leads to small errors in the result is not necessarily true. Hence, we conclude that it is important to rely on an analytical estimate of reorientation paramters, and that the inclusion of all sensor components in the process of this estimation is important. By introducing our new approach to the correction of sensor mis-alignment, we can overcome the dependency on approximative solutions and eliminate systematic sources of errors in standard time-series data processing.

References:

Grigoli, F., Cesca, S., Dahm, T., Krieger, L. (2012); *A complex linear least-squares method to derive relative and absolute orientations of seismic sensors*; Geophysical Journal International; 188(3); 1243-1254.

Krieger, L. & Grigoli, F. (2015); *Optimal reorientation of geophysical sensors: A quaternion-based analytical solution*; Geophysics; 80(2); F1-F12.

Keywords: 2D/3D sensor re-orientation, Algorithm, Quaternions, Vertical Seismic Profile, Ocean Bottom Seismometers, Array seismology

Japan Geoscience Union Meeting 2015
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STT13-17 Room:102A Time:May 28 15:00-15:15

Applicability of prestack equivalent offset migration of reflection seismic data

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Recently equivalent offset migration (EOM) has been applied to image the subsurface structure in seismic surveys. In the present study, we investigate the effectiveness of EOM for complex geological structures with inclined layers using numerical simulations. In our experiments, the geological boundaries have different dipping angles. We estimate the underground structure using EOM, and compare the result with that from dip moveout (DMO) which is a popular method for the dipping structures. The result of EOM achieve similar resolution to DMO whereas the computational cost of EOM is fifth part of that of DMO. Our result indicates that EOM has advantage over DMO.

Keywords: Prestack equivalent offset migration, Common scattering point

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-18 Room:102A Time:May 28 15:15-15:30

Applicability of Full Waveform Inversion in Sonic Logging

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Sonic logging has been widely used for many years to acquire physical properties of hydrocarbon reservoirs. Velocity analysis had been initially performed by the detection of first break, that was later replaced by slowness time coherence (STC) method using full waveform acquisition, since the estimation of velocity is important for the identification of fluid contacts such as OWC (Oil-Water Contact), GOC (Gas-Oil Contact), etc.The resolution of existing methods is restricted to 6 inch defined by neighboring receiver distance of logging tool.However, there is significant needs to gain the resolution higher than the current detection of fluid contact locations.

We, therefore, tried to introduce the method of full-waveform inversion (FWI) as an innovative technique to acquire high resolution velocity structure in the subsurface, since the method has been proven as a technique that provides higher resolution than the conventional seismic reflection methods.Since the applicability of FWI to the sonic logging has not been revealed yet, we first examined the applicability of FWI using numerical experiments.

Our results show that both GOC and OWC can be detected with the resolution higher than the conventional sonic methods whose resolution is 6 inches.We conclude that FWI would be applicable to sonic logging as a high resolution technology.

Keywords: FWI, OWC, GOC

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

STT13-19 Room:102A Time:May 28 15:30-15:45

Density parameter estimation in full waveform well-to-well tomography

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[1]Kyoto university

The importance using the full waveform is widely recognized in seismic explorations. Especially, seismic full waveform inversion (FWI) can detect the high-resolution physical properties in the subsurface. Since the seismic wave propagation cannot be controlled by not only P-wave and S-wave velocities but the density of the medium, it is necessary to include all three parameters in the modeling and inversion (Vireux and Operto, 2009). However, multi-parameter FWI is a challenging problem because parameters are coupled with each other, and the coupling effects prevent from the appropriate estimation of the elastic parameters. Especially, the estimation of density is a very difficult issue because plural elastic parameters including density increases the dimension of the solution space, so that any minimization could be easily trapped in local minima. Therefore, the density is typically estimated using an empirical formula such as the well-known Gardner's relationship (Gardner et al., 1974) or is fixed to a constant value. Since the density parameter is directly included in the elastic wave equation, it is necessary to check whether it is possible to estimate density value exactly or not. Moreover, the Gardner's relationship is an empirical equation and could not always show the proper relation between Vp and density(e.g., in the salt dome). Pre-salt exploration conducted in recent decades could accordingly be influenced.

The objective of this study is to investigate the feasibility of the estimation of density structure when the density is inverted with the other elastic parameters and to assess if density is separable from the other parameters. We perform 2D numerical simulations in order to investigate the most important factor in the inversion of density structure as well as Vp and Vs. We conducted four numerical experiments with different inversion strategies; i.e. we invert 1) Vp and density simultaneously, 2) Vs and density simultaneously, 3) Vp, Vs and density simultaneously, and 4) only density. Considering these results, the density inversion results are affected by the other parameters and inversion results are worse than the result of inverting solely density. Compared with the other parameters, the density has a little influence on the waveform, and it is likely to be ignored in the inversion. Moreover, we conducted grid analysis of misfit function (Gholami et al., 2013) to estimate the contribution of each parameter to misfit function. These results suggest that solely inversion of density is the most effective to estimate the reliable value, on the other hand to estimate density with the other parameters is captured in the local minima.

Keywords: full waveform inversion, density

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STT13-20 Room:102A Time:May 28 15:45-16:00

Full waveform inversion for subsurface exploration using vertical cable seismic data

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[1]JGI, Inc., [2]Kyoto University

Subsurface exploration for natural resources is mainly conducted by surface seismic experiments which use receiver arrays on the surface to record the propagated energy from seismic sources and produce an image of the earth after processing. Sources and receivers could be placed on the ground, i.e. land acquisition, or towed in the sea by a vessel, i.e. marine acquisition, in order to cover the desired area of the imaging. This requires appropriate data acquisition geometry and optimized data processing flows for reliable subsurface images. However, when the target is a small area in the marine environment with certain obstacles like platforms or buoys, in the deep sea conditions, or in the geologically complex areas the surface seismic exploration fails to deliver a high resolution image either because of the restrictions in the data acquisition or inefficiency of the data processing algorithms. Instead, a Vertical Cable Seismic (VCS) experiment provides a high resolution image for the investigation of the natural resources below sea floor. In the VCS configuration vertical arrays of hydrophones are deployed near the sea floor and are kept in the vertical situation by using an anchor in the bottom and a buoy at the top of the cable. Seismic source is towed by the vessel and the data is recorded for every shot point, then processing and Pre-Stack Depth Migration (PSDM) of the data yields an image of the structures. However, a good PSDM section is achieved only if accurate wave velocity model is available for the migration. Full Waveform Inversion (FWI) of the seismic data is a reliable tool to reconstruct the subsurface properties by using pre-stack recorded data. We use full waveform inversion of the acoustic data recorded by a VCS simulated experiment to develop P wave velocity model.

In the FWI workflow acoustic wave equation is solved using 2D finite difference method to produce waveforms using an initial model. Then, misfit between recorded and simulated waveforms is minimized via a local optimization algorithm, e.g. preconditioned conjugate gradient, to update the model. This process is iterated until a convergence criteria is satisfied or the maximum number of FWI iterations is reached. Because of the nonlinearity of the problem, a good initial model which is close enough to the exact solution is necessary. For the simulated experiment, we considered a marine environment with water depth of 900 m and lateral extension of 5000 m. We used four vertical cables located near the sea floor in the middle of the model area. Each vertical cable has 8 hydrophones spaced every 10 m and the deepest hydrophone is 10 m above the sea floor. Seismic sources are located 10 m beneath sea level and 500 shots at every 10 m are used for the VCS experiment. VCS experiment showed reliable results to prove that it is very useful for high resolution imaging of a small area in the subsurface, which is not practically resolvable by using surface seismic experiments.

Keywords: full waveform inversion, vertical cable seismic, acoustic

Japan Geoscience Union Meeting 2015
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STT13-21 Room:102A Time:May 28 16:15-16:30

An adaptive resolution FWI using a mesh-free finite-difference method

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[1]Kyoto Univ.

We developed an adaptive resolution full-waveform inversion (FWI) using a mesh-free finite-difference method (MF-FDM). The conventional finite-different methods (FDMs) have been widely used to calculate full-waveform synthetic traces in FWI. Most of FDMs are based on the assumption of the regular alignment of computational grids. This causes the computational burdens if the analysis model includes large velocity contrast, e.g. salt dome model. We propose a strategy to use MF-FDM for reducing computational cost in simple and seamless manners. Since MF-FDM calculates full-waveform synthetic trace with irregular distribution of nodes, our strategy can arranges adaptive resolution nodes depend on the velocity structure, i.e. fine nodes are used only around low velocity zones. We investigate the effectiveness of the method using some numerical experiments. Our results indicate that the method can successfully reduce the computational cost in simple and seamless manners.

Keywords: full-waveform inversion, mesh-free finite-difference method, numerical simulation

Japan Geoscience Union Meeting 2015
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STT13-22 Room:102A Time:May 28 16:30-16:45

Influence of pre-existing fracture and viscosity of injected fluid on effective hydraulic fracturing

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Hydraulic fracturing has been applied for enhanced recovery of hydrocarbon reservoirs and enhanced geothermal systems. In this technique, rock mass is fractured by applying fluid pressure on borehole wall. For the estimation of the propagation of hydraulically induced fractures, the strike of pre-existing fractures and the viscosity of injected fluid should be taken into consideration. Although theoretical solution shows that hydraulically induced fracture propagates in the direction of maximum principle stress in a homogeneous medium, the propagation direction in real field does not always correspond to the expected direction from the regional stress due to pre-existing fractures. The viscosity of injected fluid also influences the behavior of hydraulic fractures. The injection of high viscous fluid could improve the permeability of rock and enhance the effectiveness of the hydraulic fracturing. In order to examine the influence of pre-existing fractures and of injected fluid viscosity on the propagation of hydraulic fractures, we performed a series of numerical simulations for hydraulic fracturing in naturally fractured rock by using a 2D flow-coupled discrete element method. In our simulations, fluid pressure is applied to a borehole wall, and hydraulically induced fracture would intersect with an inclined pre-existing fracture adjacent to the borehole. We perform simulations with three different strike angles of the pre-existing fracture, using two different viscosity of fluid. As a result, hydraulic fracture propagates beyond the pre-existing fracture when high viscous fluid is injected, while it is trapped by the pre-existing fracture in the low viscous fluid injection. This is caused by the strong fluid pressure on the borehole wall and the surface of the pre-existing fracture in the high viscosity case. The results also show that the higher the intersection angle of hydraulic fracture and pre-existing fracture is, the more hydraulic fracture propagation is retarded. We conclude that high viscous fluid could be recommended for effective hydraulic fracturing when the hydraulic fracture has high intersection angle to pre-existing fracture.

Keywords: Hydraulic Fracturing, Discrete Element Method, Viscosity, Pre-existing Fracture

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STT13-23 Room:102A Time:May 28 16:45-17:00

Fracture propagation stimulated by hydraulic injection under in-situ stress field

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Hydraulic fracturing is a major scheme for improving the production of non-conventional energy resource as well as horizontal well. It increases the permeability of reservoirs which is usually tight and low permeability by making fracture net in the reservoirs. Acoustic Emittion (AE) is observed on the ground surface or in observation wells to monitor the expansion of the fracture net by fluid injection. Laboratory experiments indicate that hydraulic fractures would propagate in the direction of the maximum principal stress around the fractures. Hence it is assumed that in-situ stress could play an important role for the behavior of hydraulic fracture propagation in the field scale. It is, however, difficult to observe the fracture propagation directly due to the depth of the reservoir layer (>2km generally). Therefore, the ratio of tensile crack to shear one induced by the fluid injection has not been revealed yet.

Distinct element method (DEM) has often been applied to the simulation of the hydraulic fracturing, which shows the fracturing mechanism around the injection well, while it has a limit of analytical area around the borehole due to the computational cost. It is, therefore, challenging to simulate hydraulic fracturing in the real scale (>10m). In this study, we adopted the extended finite element method (X-FEM) and add a new degree of freedom for the effects of the fluid inside the fracture (Chen 2013). We optimized this scheme to simulate the fracture propagation in the large scale under in-situ stress field. The advantages of this scheme are following. a) Fractures are defined independent of the mesh, which could reduce the computational cost due to the re-meshing process. b) It maintains the continuity of displacement at each node on the elements. It would bring stable stress field and fracture simulations. We developed the hydraulic fracturing simulation tools with this scheme and explored the mechanism of fracture propagation triggered by the fluid injection.

For the evaluation of the fracture propagation, we made a simulation model in real scale and put external forces as in-situ stress. The aim of this simulation is to investigate the influence of the in-situ stress on the fracture propagation and fracturing mechanics. To understand the effect of the stress field around the fracture tip, we also created a heterogeneous model of P-wave velocity. We conducted two simulations with the homogeneous and heterogeneous models, and obtained the characteristics of the fracture propagation in the geological formation.

The first result, using the homogeneous model, shows that fracture propagates with not only tensile but also shear stress components even if the injected fluid inside the fracture presses outward. It suggests that hydraulic fractures could generate mixed-mode crack. The second result from the heterogeneous model simulations indicates that the in-situ stress field could be disturbed by the heterogeneity and the fractures no longer propagate simply in the direction to the maximum principal stress from far field. It indicates that while fractures propagate in a linear fashion in the homogeneous model, they propagate in a turbulent manner in the heterogeneous model.

We investigated the influence of the in-situ stress field on the hydraulic fracture propagations in the geological layer. It is suggested that the hydraulic fractures would propagate with both tensile and shear crack that is mixed-mode cracks. In addition, the macroscopic heterogeneity in the subsurface could affect the behavior of the microscopic fracture propagation. These results might help to estimate the radiation of the AE and evaluate the fractured reservoir in the real field.

Keywords: Hydraulic Fracturing, X-FEM, In-situ stress, Fracture propagation