Delineation of S-wave velocity structure of pavements and embankments by means of high-frequency surface wave measurements

*Tomio INAZAKI[1], Hiroshi Kisanuki[1], Koichi Hayashi[2], Sugio Imamura[3], Takaho Kita[4]

1. Public Works Research Institute, Tsukuba Central Institute, 2. OYO USA, 3. CTGK, 4. TK Ocean-Land Investigations Ltd.

Special attention should be paid not only to the surface pavement but also to such artificial layers as embankments and fills when applying near surface geophysics (NSG) to the subsurface up to 30 m depth. Conventional geophysical studies of the Earth’ s interior have ignored or treated the near surface as a nuisance or a noise source. Conversely, our social activities have fundamentally been being operated in the near surfaces. Since NSG should play an important role for assessing the present state and future deterioration potential of infrastructures mainly founded on and in the near surfaces, through delineating their heterogeneous structures, and through characterizing their physical properties such as bearing strength and seismic resistance. On the other hand, surface pavement layer, which is a quite common substance in urban areas, has made it difficult to apply seismic refraction surveying because of the velocity overturning, and the existence of a number of buried metallic pipes at shallow depths too for applying EM measurements. In contrast, seismic reflection and surface wave method have the capability of delineating velocity structures in the near surfaces even through the surface pavements. Actually we have conducted a number of near surface surveys in urban areas utilizing SH-wave type and surface wave type Land Streamers. Target depths of the surveys were from 100 m to 5m. We could expand the opportunity of applying NSG to pavement structure surveying when we make the target depth shallower than 1.5 m. One of the most useful tools for ultra-shallow surveys is GPR (Ground Penetrating Radar), and actually it has been widely used for detecting voids beneath the pavement. It can locate voids, however, but does not provide information on physical properties of pavements indispensable for road maintenance. In contrast, surface wave method can yield S-wave velocity structure of the subsurface. Our recent studies have revealed that high-frequency dispersion curves up to 500 Hz were obtained by means of the Land Streamer, developed by the first author, which mounted a conventional 4.5 Hz geophone on a metallic baseplate coupled non-adhesively with pavement surface. In addition, we demonstrated that an accelerometer array tool had wide frequency range up to 4 kHz, but adhesion of accelerometer sensors, it forced time-consuming and dangerous works on roadways, were critical for obtaining high quality records. Dispersion curves up to 4 kHz enabled us to reconstruct S-wave velocity structures at depths of 15 cm to 2 m or more. It was required to obtain dispersion curves up to 8 kHz for the estimation of S-wave velocity and thickness of the uppermost asphalt concrete layer, which was the key for assessing traveling performance of roadway. Then we newly developed a non-contact surface wave measurement tool using an air-coupled microphone array for the structural investigation of pavements. The tool comprises two microphone arrays, suspended 2 cm above the pavement surface. The microphone array observes leaky surface waves under air-coupled condition. Field measurements demonstrated that the tool could measure surface waves which showed clear dispersion in the frequency range from 40 to 8,000 Hz. S-wave velocity structure of the pavement up to 1 m was successfully reconstructed from the higher modes or Lamb mode of surface waves. To certify whether the dispersion curves measured by the tool were valid, we conducted check drilling and forward modelling based on the drilling data. Observed dispersion curves were well matched with those calculated from the actual pavement structure.

Keywords: surface wave, leaky surface wave, high frequency, higher mode, artificial layer

Development of a method to estimate one-dimensional distribution of dielectric constant using electromagnetic waves

*Akira Furukawa[1], Kanta Takagi[1], Sohichi Hirose[1], Yoshiaki Yamanaka[2], Hiroshi Imai[2]

1. Tokyo Institute of Technology, 2. SUNCOH CONSULTANTS CO., Ltd.

It is important to monitor water distribution under the ground near repository sites of radioactive waste. Water content in the ground and rocks can be evaluated via electromagnetic wave analysis. Electromagnetic wave analysis has advantages to evaluate water content for the following reasons: (1) The existence of pore water provides significant change in dielectric constant. (2) There is a relation between dielectric constant and degree of saturation. However, it is difficult to evaluate the distribution of dielectric constant in wave propagation direction by existing methods which are based on information of arrival time and amplitude of electromagnetic waves reflected from gap of dielectric constant.
This study presents a method to estimate the distribution of dielectric constant via electromagnetic wave analysis. The proposed method consists of an unscented Kalman filter and a finite element method. The unscented Kalman filter is a nonlinear Kalman filter which can evaluate state values of a nonlinear system from observation signals with zero-mean Gaussian noise. In the estimation process, the nonlinear Kalman filter requires computation of nonlinear transform. In this study, the computation of a nonlinear transform corresponds to the FEM analysis of reflected electromagnetic waves for arbitrary distribution of dielectric constant.
The validity and performance of our proposed method have been confirmed by numerical and laboratory experiments. In numerical experiments, reflected electromagnetic waves computed by FEM are used as observed signals. The estimated distribution of dielectric constant is in good agreement with the correct distribution. In laboratory experiments, reflected waves measured by a ground penetrating radar (GPR) are used as observed signals. The estimation results are not well fitted with the distributions expected. One of the reasons is that finite element analysis doesn’t consider the effects of wave attenuation, and this problem is a future task of this study.

Keywords: Electromagnetic wave, Distribution of dielectric constant, Unscented Kalman filter

Processing of ground penetrating radar (GPR) data for underground cavity by Convolution neural network

*Shinichiro Iso[1], Akira Saito[1], Kyosuke Onishi[2], Toshifumi Matsuoka[3], Yukio Tobe[4], Toru Takahashi[3]

1. Graduate School of Creative Science and Engineering Dept. of Resources and Environmental Engineering, 2. Public Works Resarch Institute, 3. Fukada Geological Institute, 4. Geofive Co., Ltd.

Title

Processing of ground penetrating radar (GPR) data for underground cavity by Convolution neural network

Background

For many years, GPR (Ground Penetrating Radar) systems have being used to detect cavities underneath the road surface. A system on a vehicle are available to acquire a large amount of data with multi channels, such as 21 channels, faster than about 40 km/h driving. Amount of the data has become larger and larger. The accumulated surveyed road path is supposed to more than 150, 000 km.
Today, the experts take a long time to inspect visually such massive data to identify cavities. It also takes years to become a skilled expert. These years, besides development of the new machine learning design, the Machine Learning and parallel computation technology, such as Deep Learning and GPU frameworks and computer hardware show drastic improvement.
Deep Learning approach is supposed to work with the acquired data directly and automatically. It means that automation of recognition and classification of the types of reflectors with the acquired data directly. In addition, the learning network can be improved with the accumulated training data less computation effort as a transfer leraning. Such feature will fit the analysis of the GPR data for underground cavity survey.
Iso et. al. presented “Processing of ground penetrating radar (GPR) data for underground cavity survey by deep learning”, at the 135th SEGJ Conference in 2016 in Japan. It shows a possibility of the being effective of usage of Deep Learning to distinguish cavities, metal pipes and others for 2D GPR cross-section. However, this previous study, in order to classify the target reflectors, users need to pick the specific reflection anomaly, the top of the shape of hyperbolic curves, manually. The classification result failed in some cases, even though considering amount of training data is limited.

Purpose

The aims of new study are 1) eliminating the manipulation of users to pick the target reflectors and 2) mitigating the errors of cavity classification, with the new Deep Learning network. Besides the limited training data, the problems are supposed to be caused by the limitations of the Learning Network design in the previous study. It uses Deep Neural Network with the hidden three layers as a Deep Learning. This is a simple learning network, and it may not be fit to find out the target objective in the large image region. The new study uses the Convolution Neural Network, CNN, design as a Deep Learning to distinguish and locate cavities and the others. The CNN is one of the feed-forward artificial neural network and widely used for 2D image recognition in the other industries these years. The study bases the real acquired data for training images and evaluate with the other set of real 2D GPR data.

Conclusion / Discussion

The results are compared and discussed with the previous study to the recognition accuracy and efficiency of training effort (CPU time and training images) for initial training and transfer learning.

Keywords: Deep Learning, GPR, Automation, data processing, road inspection, cavity survey

Detailed GPR survey for delineating boulders buried in a roadbed of a highway under construction

*Kunio Aoike[1], Hiroshi Kisanuki[2], Takanori Ogahara[2], Tomio Inazaki[2]

1. Oyo corporation, 2. Public Works Research Institute

We conducted a detailed GPR survey on a highway under construction to detect and map boulders in a roadbed buried against regulations on embankment materials. Buried boulders in roadbeds should be eliminated because they might cause surface pavement undulation and would deteriorate drivability. A 540 m long, 20 m wide zone was covered within three days by two parties, each composed of two of us, by means of two sets of high-precision GPR tools with the aid of VRS RTK-GNSS positioning systems. Soon after the primary field survey, we quickly processed the acquired data within two days, and extracted a total of 148 anomalies in the zone. We then conducted the secondary survey uninterruptedly to precisely locate the points where anomalies were identified. The located points were immediately dug with a backhoe to certify whether boulders had been buried or not. It took only one and half day for the secondary field survey. As a result, boulders of 20 cm to 100 cm in size were actually excavated from 146 points of the located 148 anomaly points. This extremely high hitting ratio was mainly supported by the precise positioning system which enabled us to locate back to the anomaly position within 2 cm. In addition, we made a criterion to discriminate the anomalies generated from buried boulders based on GPR diffraction patterns. The criterion was quite helpful to identify anomalies from buried boulders not from other objects such as metal fragments. Owing to the high performance GPR survey within a total of 6.5 days from the primary survey to the excavation of identified boulders, we successfully contributed to minimize the delay in embankment works of the highway under construction.

Keywords: Highway geophysics, GPR, roadbed, boulder

Evaluation of groundwater in fractures adjacent to tunnel using information of waveforms of Ground Penetrating Radar

*Kazuhiko Masumoto[1]

1. Kajima Corporation

For construction of underground structures in a rock, it is important to characterize the ground water flow in the fracture. Fractures developing around the tunnel during the excavation, which is called as EDZ (Excavation Damaged Zone), result in issues related not only to the mechanical stability of the rock cavern, but also to the groundwater flow paths. Specifically, in terms of the safety assessment of geological disposal of radioactive waste, the groundwater management of rock caverns for oil/LPG storage using hydraulic containment system, or planning of countermeasures for water seepage of tunnels, it is important to have a thorough understanding of the groundwater conditions around the tunnel.
As the GPR (Ground Penetrating Radar) method is unique technique to survey the groundwater condition, indirectly, and with no disturbance of original ground water condition, so the GPR is possible to grasp the water condition in the fractures around the tunnel, however, the output is just the profile image of the fractures so far. In this study, the change of reflected waveforms (amplitude or frequency) of GPR is focused in order to estimate the water content and concentration of liquid in the fractures, and the target of this study is to show the possibility of application of the information of GPR waveforms to evaluate the groundwater in the fractures.
Firstly, based on the results of theoretical discussion of electromagnetic wave and numerical simulation using FDTD method, it was concluded that the change of water content, saturated or non-saturated condition and the existence of high conductivity reflector have influence on the waveforms, that is, the change of amplitude and dominant frequency of reflected wave. So, the change of amplitude and frequency would be a possible indicator to evaluate the water condition in the fractures.
Next, in order to validate the possibility of application of GPR in the actual site, three types of experimental study were conducted; (1) preliminary test using the artificial fractures, which consisted of the wooden cement-boards between a concrete block (Masumoto and Kurihara, 2014), (2) verification test on the surface of the concrete placed on the granitic rock with fractures to evaluate groundwater permeation in the rock of lining backfaces (Masumoto and Kurihara, 2015), (3) verification test along the side wall of 500m access tunnel of Mizunami Underground Research Laboratory of JAEA to estimate the fractures around the tunnel as flow paths (Masumoto and Takeuchi, 2016).
From these results of monitoring of the reflected waveforms from the target fractures using GPR, it could be concluded that the difference of water condition in the fractures caused the change of intense of amplitude and spectrum due to the results of spectrum analysis of reflected waveforms. The results indicated that the water condition in the fractures and the flow paths or transport channels along the fractures could be evaluated using the information of reflected waveforms of GPR.
In the future, this non-destructive method using GPR could be applied to monitor the submerge process of unsaturated zones around rock caverns, to measure the break-through process in tracer tests 2-dimensionally, and to monitor the permeation of grouting materials in grouting work.

References:

Masumoto, K. and Kurihara, K. (2014): Experimental study using artificial fractures for application of ground penetrating radar to survey groundwater flow in a fractured rock mass, Journal of Japan Society of Engineering Geology, Vol.55, No.1, pp.17-27.

Masumoto, K. and Kurihara, K. (2015): Evaluation of groundwater condition in fractures around rock cavern using ground penetrating radar, Proceedings of 43rd Symposium on Rock Mechanics, pp.188-192.
Masumoto, K. and Takeuchi, R. (2016): Evaluation of fractures in a rock as flow paths around tunnel using ground penetrating radar, Journal of Japan Society of Engineering Geology, Vol.57, No.4, pp.154-161.

Keywords: Ground Penetrating Radar, Excavation Damaged Zone, Groundwater

Resistivity monitoring of water-leaking paddy field filled with water

*Keisuke Inoue[1], Kosuke Wakasugi[1], Yasuyuki Wakiyama[1], Ryosuke Nomiyama[1], Seiji Tanaka[2]

1. National Agriculture and Food Research Organization, 2. Kumamoto Prefectural Agricultural Research Center

A large earthquake causes high hydraulic conductivity zones in the soil and the high hydraulic conductivity zones of soil often lead to leakage of water from a paddy field. Although the locations of infiltration have to be estimated, the locations cannot be observed from the surface. Electrical resistivity survey can provide spatial geological information non-invasively because electrical resistivity is strongly affected by the level of water saturation in the soil. After the 2016 Kumamoto earthquake occurred, although the amount of leakage from a paddy field increased, the location of infiltration was not observed. In this study, resistivity monitoring of a water-leaking paddy field filled with water was conducted. A resistivity change derived from 2D inversion of resistivity survey data was small beneath the paddy field and the resistivity beneath the bank of the paddy decreased 4 hr. after the start of filling with water. Since some rain occurred before the filling test, there was a possibility that the high saturation level caused no change beneath the paddy field. However, the resistivity beneath the paddy flied decrease 24 hr. after the start of filling with water.
These results suggest that the leakage occurred beneath the bank of the paddy rather than beneath the paddy field.

This work was financially supported in part by Science and technology research promotion program for agriculture, forestry, fisheries and food industry.

Keywords: Resistivity monitoring, water-leaking paddy field, earthquake

Imaging of the internal geophysical structure by means of near surface geophysical surveys at a road embankment failure site.

*Hiroshi Kisanuki[1], Takanori Ogahara[1], Kyosuke Onishi[1], Tomio INAZAKI[1]

1. Public Works Research Institute

A road embankment which is about 8 m high was partly collapsed by a heavy rainfall. This embankment had been experienced a strong shaking two months before the collapsing caused by the 2016 Kumamoto earthquake. Surface cracks and deformation were identified on the body just after the earthquake. We conducted near surface geophysical survey to clarify a collapse process and internal geophysical structure of survived part of the road body. Our survey consisted of GPR and DC resistivity tomography. We used Utility scan DF system synchronized with GNSS antenna for a GPR survey. This system can obtain high accuracy positioning data within +/- 1 cm under RTK-FIX condition. In DC resistivity survey, current and potential electrodes were set alternately at 50 cm intervals along a line which cross at a collapsed part. As a result, GPR profile imaged a dipping structure behind the collapsed part. Resistivity structure showed relatively high resistivity as the embankment and imaged frontal thrust clearly. A possible sliding surface was interpreted on the basis of resistivity structure and surface displacement trajectory between before and after collapse of 5 points. In conclusion, GPR and DC resistivity tomography was helpful to delineate internal deformation structure and interpret a possible sliding surface. The survey result demonstrated the effectivity of detailed near surface geophysical surveys.

Keywords: Embankment failure, Near surface geophysics

Geoelectrical monitoring of changes in water content in an embankment using a large-scale rainfall simulator

*Shinichi Takakura[1], Mayumi Yoshioka[1], Naoki Sakai[2], Tomohiro Ishizawa[2], Toru Danjo[2]

1. National Institute of Advanced Industrial Science and Technology, 2. National Research Institute for Earth Science and Disaster Resilience

Measuring the temporal variation of water content in a slope is important for preventing slope disasters. We conducted repeated monthly geoelectrical surveys since February 2011 on one slope of an embankment in the large-scale rainfall simulator of the National Research Institute for Earth Science and Disaster Resilience (NIED). A survey line, which is 18m in length, was set up across the slope. Thirty-seven electrodes were arranged permanently at 0.5-m intervals along the line. Measurements of near-surface soil water content and temperature have been conducted at five places along the line. The embankment is usually outdoors and observations in natural weather have been performed. The results of the repeated geoelectrical surveys show that short-term changes in resistivity correspond to changes in water content caused by rainfall.
In order to confirm the changes in resistivity and water content by rainfall in detail, we conducted the artificial rain experiments, controlling the total amount and intensity of rainfall using the mobile simulator. Eleven experiments were conducted in 2012, 2013, 2014. It was difficult to obtain the rapid change of resistivity structure due to the heavy artificial rain with ordinary geoelectrical equipment, because the analysis of resistivity structure requires measurement by much electrode array combination. In these experiments, therefore, we performed only a continuous measurement using a Wenner array with “a” spacing of 0.5 m and 1 m. The apparent resistivities changed significantly with a rapid change in water content, indicating that geoelectrical monitoring is effective in assessing the condition of a slope during rainfall.
In three experiments in 2015, we used a high-speed resistivity profiling system which can provide 576 (24x24) data in about 10 seconds for the resistivity monitoring. The pole-pole resistivity data were collected at intervals of 1 or 2 minutes and a series of resistivity sections were obtained along the slope of the embankment. The result shows that the high-speed geoelectrical monitoring is effective for observing soil moisture changes caused by heavy rain in real time.

Keywords: Geoelectrical monitoring, resistivity, water content, large-scale rainfall simulator, slope disaster

Case studies of the survey of induction method using GEM-2 -- along the sand beach and above the intrusive rock --

*Shin'ya Sakanaka[1], Yuki Takatsuto[2], Junya Maruyama[1], Yusuke Inoue[1], Takuya Kobayashi[1]

1. Graduate school of International Resource Sciences, Akita University, 2. JR East

GEM-2 is the electromagnetic instrument used in this study. Since it can simultaneously operate multiple frequencies in the broadband domain from 300 Hz to 96 kHz, we will be able to estimate the distribution of the conductivity to the depth direction. The purposes in this study are detection of the boundary of freshwater of the creek and seawater at Katsurahama coast in Akita city and examination on the anomaly of the electrical conductivity above the intrusive rock at the quarry site in Sugisawa, Daisen city, Akita prefecture.
On the exploration at Katsurahama coast, the freshwater of the creek has the characteristics of the low electrical conductivity of 0 to 40 mS/m. On the other hand, the high electrical conductivity is seen on a part of the western sea side. The change in the low conductivity to the depth beneath the creek cannot be observed, but on the part of the high conductivity on the sea side the change to the depth can be detected. The conductivity is higher at the shallower depth compared with deeper place at the part of the high conductive western sea side. I consider that the high electrical conductivity of the shallow sea side is more influenced by the invasion of the seawater.
At the quarry site in Sugisawa, the anomaly of the low electrical conductivity surrounded by the high conductivity is seen above the intrusive rock by the exploration. The distribution of the high electrical conductivity is considered to be due to alternation and mineralization in the contact part of intrusive rock and pre-existed rock. Examining the tendency of the depth change of the distribution of the low conductivity surrounded by the high conductivity above the intrusive rock, it is said that the structure change cannot be seen to the depth from 5 to 19 m.
I understand that the resolution by the exploration using GEM-2 is excellent at shallow depth, but that GEM-2 is easy to catch the noise when the exploration depth exceeds 10 m. In other words, GEM-2 is easy to catch the noise when we operate it with low frequencies. It is sometimes necessary to remove noises on low frequency operation. In this study, I successfully remove the noises and improve the data with taking the median values and using the running mean method on a finite length of data section.

Keywords: electromagnetic survey, induction method, GEM-2, freshwater/seawater interface

Changes in phase velocity of Rayleigh waves at the Hinode area, Itako, Ibaraki, Japan, due to the construction by the ground water lowering method: A case study of the miniature array analysis of microtremors

*Ikuo Cho[1], Tishiyuki Yokota[1], Shigeki Senna[2]

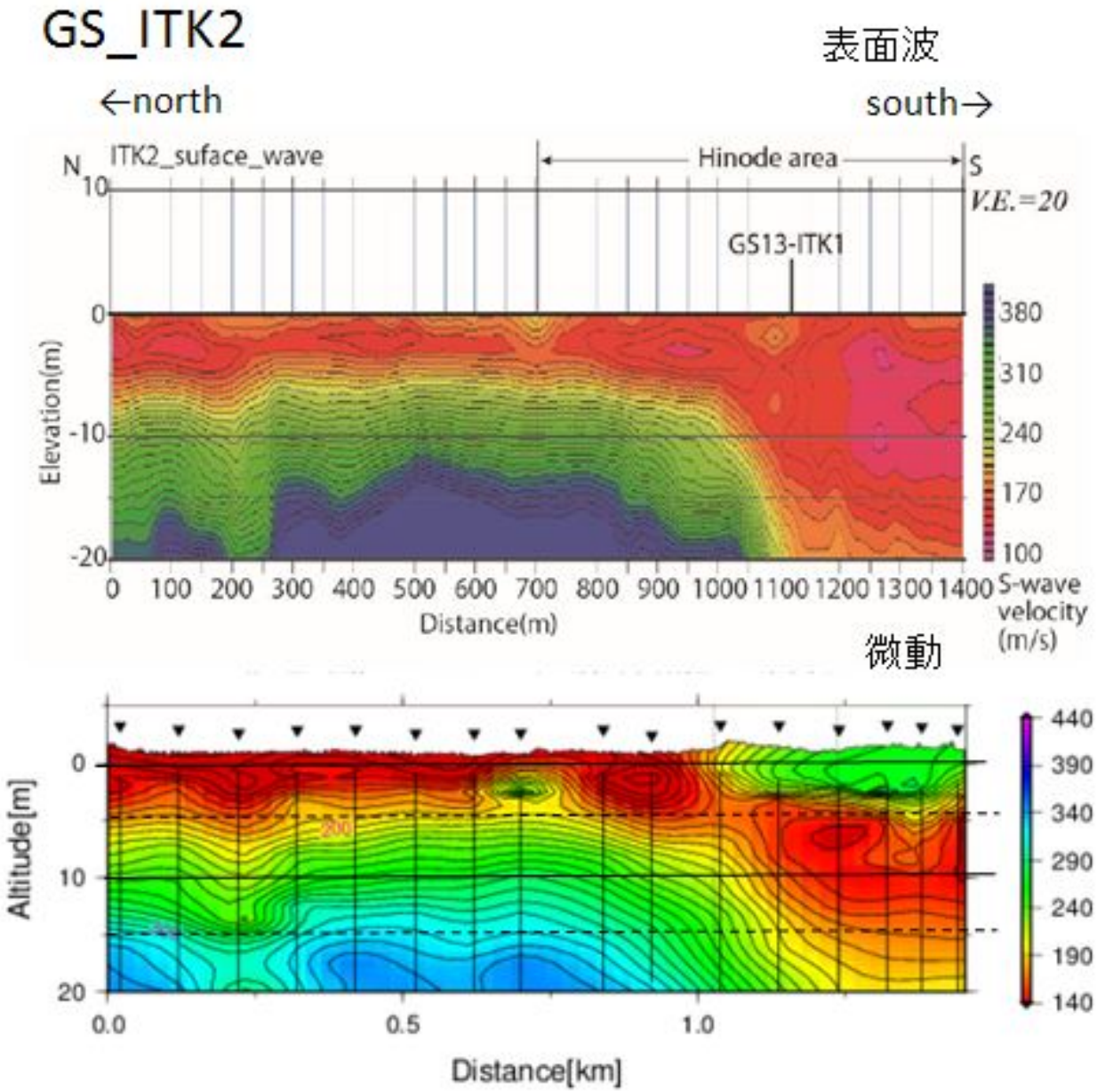
1. National Institute of Advanced Industrial Science and Technology, 2. National Research Institute for Earth Science and Disaster Prevention

The Hinode area, Itako, Ibaraki, Japan suffered devastating disasters of liquefaction by the 2011 off the Pacific coast of Tohoku Earthquake. The Itako City has been conducting the construction method called the ground water lowering method to avoid the second devastating liquefaction by some huge earthquakes in the future. We report the changes in phase velocity of the Rayleigh waves at the Hinode area between two periods before and after the construction work starting, as a case study of the miniature array analysis of microtremors (Cho et al., 2013).
The construction period of the ground water lowering method was from April 2013 to March 2016. Currently, drain pipes has been buried at the depth of 3m along all paved roads in the Hinode area following that method. The ground water has been pumped up since May 2016. It is evaluated that a large liquefaction will never be met again by lowering the water level to the depth of 3m and keeping it at all times (Itako City, 2016).
We conducted measurements of microtremors using miniature arrays at an interval about 200m along an east-west survey line with the length of 3.2km, which crossed the Hinode area (about 2.8x1.4km) and its surroundings. The microtremor array used there was basically a set of a standard four-point array with a radius of 0.6m and a three-point irregular array with a radius about five meters. The observation duration was about 15min at each point. These microtremor surveys were conducted on August 2012 and on the begging of May 2013. Meanwhile, Yokota et al. (2016) conducted surface wave surveys on December 2012 along three survey lines with lengths from 1.2 to 1.6km, which includes the Hinode area and the northern extensions. In this study, we regard the data from the east-west survey line of microtremors and the two north-south survey lines of surface waves as the "data before the construction work starting".
As the "data after the construction work starting", we conducted measurements of microtremors using miniature arrays along the above three survey lines on September and October 2015. In the field measurements, we took care that each installation point of the microtremor arrays was the same as before. We deployed microtremor arrays at the interval about 100m along the surface wave survey lines. Importantly, all measurements of microtremors were conducted by installing the seismometers on the shoulder of a paved road, so that it is expected that the data after the construction work starting include the direct effects of the construction.
We analyzed the microtremor data along the east-west survey line and compared between the dispersion curves from the data before and after the construction work starting. As the result, it was shown that phase velocities obtained within the Hinode area increased especially in high frequency ranges. On the basis of a simple conversion method from a dispersion curve to an S-wave structure, these changes appeared to correspond to the increase in the S-wave velocities to the depths shallower than several meters. Similar features can be seen in the S-wave structures obtained by the microtremor method along the two survey lines of surface waves. This means that the general pattern of the distribution of the S-wave velocity obtained by the microtremor method is very similar to that obtained by the surface wave method with the exception of one point: the S-wave velocities to the depths shallower than several meters in the Hinode area by the microtremor method was particularly high (Fig. 1).

In this way, we observed changes in S-wave velocity only in the shallow portions in the Hinode area. This is qualitatively natural and may show the potential of the miniature array analysis of microtremors. We will make detailed examinations on the limitation and possibility of the miniature arrays in more qualitative manner.

Cho et al., 2013, Geophysics, 78, KS13-KS23.
Itako City, 2016, http://www.city.itako.lg.jp.
Yokota et al., 2016, Exploration Geophysics (in press).

Keywords: microtremor, array, surface wave, liquefaction, the 2011 off the Pacific coast of Tohoku Earthquake, the ground water lowering method



Distrubution of saline-freshwater in shallow groundwater in the lower reaches of Nabaki River, the Kujukuri Plain, Chiba Prefecture, Japan

*Yuka Ito[1], Xinren Zhang[1], Tomochika Tokunaga[1], Katsuro Mogi[1]

1. School of Frontier Sciences, The University of Tokyo

Kujukuri Plain, Chiba Prefecture is a coastal area, which is of low topography and also one of the places in where land subsidence is reported to have been occurring for over 40 years. Nabaki River is a tidal river located in the sourth of the Kujukuri Plain and the seawater flowing into the river from the mouth at high tide time is reported. Therefore, the distribution of salt and fresh groundwater and possible influence of the tidal river to the surrounding groundwater is required to understand. In this study, we discuss to reveal the distribution of salt-fresh groundwater and a process of groudwater salinization by the method of resistivity survey and water chemistry. The overall tendency is that the shallower part of the subsurface (about 3 to 5 m) has a higher resistivity value and the deeper part (deeper than about 5 to 7 m) has a low value. It is interpreted that freshwater exists in the subsurface shallower part and groundwater with high salt concentration is distributed in the deeper part. On the other hand, in some areas, the groundwater with high salt concentration (low resistivity zone) indicated a distribution that sloped from shallow to deep with the distance from the Nabaki River, and the effect of the tidal river is suggested as one of the factors.

Keywords: Nabaki River, Resistivity survey, saline-freshwater, shallow groundwater

Characterization of the aquifer at Tottori sand dunes using NMR and GPR sounding

*Chisato Konishi[1], Kunio Aoike[1], Takayuki KAWAI[2], Kuroda Seiichiro[3]

1. OYO Corporation, 2. Tottori University, 3. Institute for Rural Engineering, NARO

We have conducted the surface NMR and GPR surveys at Arid Land Research Center, Tottori University. The surface NMR is a non-destructive survey for characterizing aquifer using loop on the ground surface which are used for transmitting and receiving coil. The NMR signal is proportional to the magnitude of the magnetic field, so the signal obtained by the surface NMR is much smaller than other NMR method such as NMR logging, because the magnetic moment of the earth is very weak. Therefore, the surface NMR is mostly difficult to apply in the suburb of an urban area. The research center is located at only a few kilometers away from the Tottori city and the EM noise level is not so small. Yet, the noise level is within the acceptable levels by noise tester. A 35 meter side eight-square loop is adopted in our survey, and total 12 pulse moments are used to obtain a full sounding curve. Only less noise data are acquired and more than 250 data are stacked to increase the signal to noise ratio. A typical NMR signal showing exponential decay curve was observed at a certain pulse moment. Full sounding result is compared with the forward modeling and we inferred that a few meters thin aquifer exist at 30 meter depth.
GPR is usually applied for shallow subsurface investigation down to a few meters deep. Especially, the penetration depth will be shallower for the heterogeneous subsurface or clayey soils. However, the penetration depth goes deeper for the homogeneous thick sand deposit such as Tottori sand dunes. We completed the profile and the CMP surveys by 35 MHz antenna. The velocity of the EM wave is calculated from the CMP measurement and we created the depth profile using the calculated EM velocity. A clear reflection boundary is observed at around 29 to 30 m depth in the depth profile. The depth of the reflection agrees with the actual water level measured at several monitoring wells in the survey area.
The surface NMR enables us to obtain one dimensional result of water table and thickness of the aquifer, while GPR provides two dimensional image of water table. Therefore, combining the two methods must be an effective method to characterize aquifer in arid area.

Keywords: Surface NMR, GPR, groundwater, Sand dune

Rock Physics Digital Library -A data and knowledge base for modeling and interpreting shallow geophysical data -

*Toru Takahashi[1]

1. Fukada Geological Institute

Fukada Geological Institute has opened a database called as Rock Physics Digital Library (RPDL) on its website, which consists of data and information about physical models for modeling and interpreting shallow geophysical data in civil and environmental engineering. Its website address is http://www.fgi.or.jp/rpdl. RPDL is composed of four kinds of data and knowledge that are geophysical and geotechnical datasets obtained in laboratory tests and well loggings, a comprehensive list of empirical relationships between geophysical and geotechnical properties, a guide of procedures for modeling of geophysical data, and a list of literatures on physical models and their applications. These data and information can be viewed on the screen and also downloaded at user’ s preference The RPDL is continuously updated by inputs of new data and information from its users as well as ourselves. This paper demonstrates the data and information available in this database, and also shows a few applications of physical models to shallow geophysical data for solving civil engineering problems.

Keywords: rock physics, database, shallow geophysical data

Detection of surface displacement and landslide blocks in the southwest area of Mt. Hakusan using interferometric SAR analysis

*Yukiyasu FUJII[1], Kazuya Ishitsuka[2], Makoto Kaneko[1], Toru Takahashi[1], Toshifumi Matsuoka[1,3]

1. Fukada Geological Institute, 2. Hokkaido University, 3. Center for the Promotion of Interdisciplinary Education and Research, Kyoto University

It is important to estimate surface displacements of landslides and discriminate active landslide blocks to take counter measures for landslide-related disaster. Interferometric SAR (InSAR) analysis, which utilizes remote sensing technology, would be a suitable method for the purpose, because the spatial distribution of surface displacement can be obtained, and active landslide blocks would be estimated. In this study, we investigated landslide surface displacement in the southwest area of Mt. Hakusan using InSAR analysis. We used SAR data acquired at 8th October 2014 and 15th July 2015 in an ascending orbit, and at 20th September 2015 and 12nd June 2016 in a descending orbit. As a result of analysis, we found landslide displacement up to 10 cm around the Jinnosukedani and Yunotani areas between October 2014 and July 2015. And, significant displacement was not estimated at the Bettoudani area. On the other hand, between September 2015 and June 2016, more broad areas displaced in the Jinnosukedani area. And, displacement was found in the northern part of the Yunotani area. From the result, we interpreted that the Yunotani area consists of several landslide blocks. Our result demonstrates that the effectiveness of InSAR analysis for monitoring around the landslide area.

Keywords: InSAR, Landslide, Monitoring

S-wave velocity structure using seismic interferometry in Zushi area

Shunpei Misumi[1], *Yoshiya Oda[1]

1. Tokyo Metropolitan University

S-wave velocity structure is very important information for earthquake disaster prevention. In recent years, study using seismic interferometry has gained rapidly in popularity. However, there are few studies estimate shallow structure. We applied seismic interferometry to estimate shallow ground structure in Zushi area.

Keywords: S-wave velocity structure, Zushi, Seismic interferometry

Seismic refraction survey on the tunnel pavement and evaluation of seismic velocity of tunnel ground surface

*Kenji OKAZAKI[1], Syusaku YAMAZAKI[1], Toshiyuki KURAHASHI[1], Yoshihiko ITO[1], Hiroumi NIWA[2], Hideyuki MURAYAMA[2]

1. Civil Engineering Research Institute for cold region, PWRI, 2. Fujita Corporation

There have been many reported cases in which deformation, such as tunnel ground heaving and squeezing of sidewalls, occurred in a tunnel days, months or even decades after construction. Therefore, a diagnostic method is required that is able to provide constant and reproducible monitoring from construction stage to maintenance stage. We are carrying out a study to develop a diagnostic method to estimate the soundness of tunnel ground from time-dependent behavior from in an actual two tunnels, the New tunnel and the Old tunnel, with time-dependent deformation. The Old tunnel was conducted after closure after opening of the New tunnel. From the results of a series of laboratory tests and field experiments, we found it is possible to estimate the soundness of tunnel ground using seismic velocity. So, we carried out field experiment of actual tunnel with time-dependent deformation and the result of case study evaluating the soundness of tunnel ground using seismic velocity. The geology of both tunnels in this study is hydrothermally altered pyroclastic rock. Heaving occurred in two sections replaced by timbering in a hydrothermally altered andesite zone in the New tunnel after completion in 2014. The Old tunnel was completed in 1977 using the timbering support method. The Old tunnel has 5 sections of time-dependent deformation. A seismic refraction survey was carried out in both tunnels in order to evaluate the soundness of tunnel ground. We used a hydraulic impactor as the seismic source and MEMS (Micro electro mechanical systems) sensors as seismic receivers. The hydraulic impactor was used to avoid damages to the pavement as a non-blasting seismic source. MEMS sensors enabled down-sizing of the survey equipment and to reduce the hours needed for receiver handling. P-wave generation was achieved using a vertical shot. Each shot is stacked 3 times at each shot point in order to improve S/N ratio. The survey line is 450 m length in the New tunnel, 1,500m in the Old tunnel. The interval of receivers is 6.0m, and the interval of shot points is 3.0m- 6.0m. If the decrease of P-wave velocity due to the time-dependent deformation or the loosening by stress release from the excavated surface, the seismic velocity in the deeper zone may be assumed to be indicate the original seismic velocity of ground because it is far from influence of the excavation. In other words, the surface part having lower seismic velocity originally had higher velocity but it decreased as tunnel excavation work progressed. Based on this assumption, the soundness of tunnel ground can be evaluated by a decrease in the ratio of surface seismic velocity to deep zone. The decrease rate of P-wave velocity of No.1 to No.5 block and non-deformed zone of the Old tunnel and the zone of initial deformation 1 and 2 of the New tunnel. The decrease rate of P-wave velocity of No.1 to No.5 block with time-dependent deformation is estimated 25% to 44%. While, the decrease rate of P-wave velocity of the other zone with no time-dependent deformation is 8% to 16%. Thus, it is confirmed that the decrease rate of P-wave velocity in the zone with time-dependent deformation is higher than that in the other zones. And it is suggested that the threshold of this tunnel ground may exist between 16% and 25%.

Keywords: tunnel, seismic velocity, time-dependent deformation

Dynamic Basement Amplification Characteristics of Dam Site using Reference Site Method

*Junkyoung Kim[1]

1. Semyung University

Observed ground motions are composed of 3 factors such as, seismic source, attenuation, and site amplification effect. Among them, site amplification characteristics should be considered significantly to estimate seismic source and attenuation characteristics with more confidence. Site effect is also necessary to estimate not only seismic hazard in seismic design engineering but also rock mechanical properties. This study applied the method of H/V spectral ratio of observed ground motion between target site and reference site, namely reference site method. In addition to using vertical Fourier spectrum of reference site, this study tried newly to use horizontal Fourier spectrum. This study analyzed H/V spectral ratio of 6 ground motions respectively, observed at 4 nearby sites at Yedang Reservoir. And then, site amplification effects at each site, using 3 kinds of seismic energies, that is, S waves, Coda waves energy, and background noise were compared each other. The results suggested that each site showed similar site amplification patterns among S waves and Coda waves energy. However, site amplification of background noise showed much different characteristics from those of S waves and Coda waves energy, suggesting that background noises at each site has it own developing mechanism. Each station showed its own characteristics of specific resonance frequency and site amplification properties in low, high and specific resonance frequency ranges. Comparison of this study to others using different method can give us much more information about dynamic amplification of sites characteristics and site classification.

Keywords: S wave, Coda wave, background noise, H/V spectral ratio, resonance frequency, reference station

Near surface geophysical survey of the ground in front of a road embankment partially collapsed by a heavy rainfall

*Tomio INAZAKI[1], Hiroshi Kisanuki[1], Takanori Ogahara[1], Kyosuke Onishi[1]

1. Public Works Research Institute, Tsukuba Central Institute

We conducted an urgent but detailed near surface geophysical survey at a site where 8 m high road embankment slope had been partly collapsed by a heavy rainfall along with strong motion of 2016 Kumamoto Earthquake 2 months before. Owing to a geotextile-anchored concrete wall preset at the foot part and 8 m long preventative pile arrays penetrated in front of the road embankment, the slope failure was minimized and debris runoff stayed in a limited zone. Meanwhile, the embankment collapse caused a half-moon shape deformation, 20 m in radius, and upheavals up to 2 m, to the ground in front of the collapse. We set a total of 4 short survey lines in and outside of the deformation zone to identify the extent of the deformation in depth direction. Employed methods were DC resistivity and “Hybrid Surface Wave Survey” recently proposed by the authors. The Hybrid Surface Wave Survey method is characterized as the combination of active and passive surface wave survey simultaneously conducted along the same seismic line. A number of geophones, set along a line at 0.5 m intervals, were used to record active surface hitting waveforms and passive microtremor. Two dispersion curves, one is for a higher frequency part calculated from active survey records, and the other is for the lower frequency part calculated from passive seismic records, were combined to form a single dispersion curve for a specific CMP in a survey line. As a result, DC resistivity measurements provided clear layered structures along the lines. Resistivity sections were concordant with estimated geologic structures but no difference was observed between the sections in and outside the deformation zone. In contrast, S-wave velocity sections showed a characteristic structure in the deformation zone. Namely, the S-wave velocities were as low as 30 m/s in the deformation zone. Thicknesses of the low velocity layer increased toward the major axis of the collapsed body up to 10 m in depth. These features were not obvious along the line set outside of the deformation zone. The field survey results demonstrates that near surface geophysics is helpful for the site characterization of landslides or slope failures on the basis of not only surface evidences but also of near surface structure.

Keywords: Near Surface Geophysics, Embankment Collapse, S-wave velocity, Resistivity

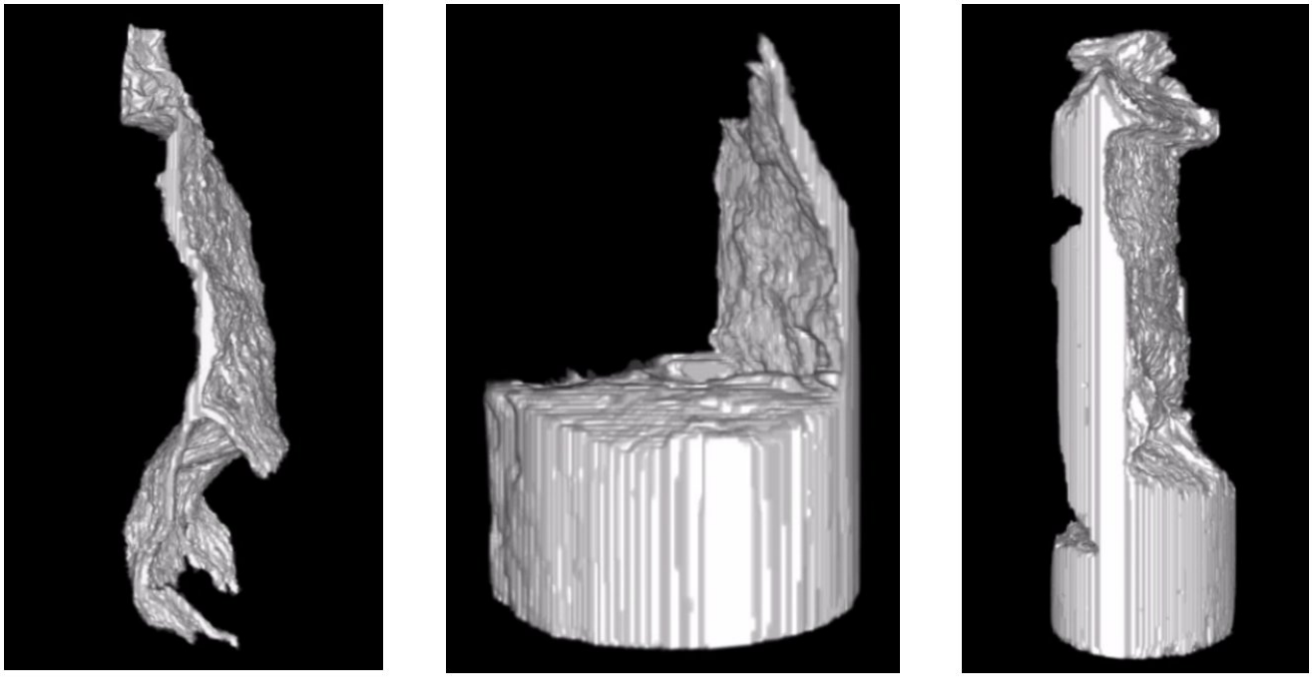
Three-dimensional structures of sand dykes revealed by X-ray computed tomography of boring cores

*Yoshito Nakashima[1], Junko Komatsubara[1]

1. National Institute of Advanced Industrial Science and Technology

Near surface geophysics is employed for the risk assessment of liquefaction induced by earthquakes. The laboratory analysis of boring cores sampled at the liquefied sites is useful for the interpretation of the obtained geophysical data because it contributes to the accurate determination of the occurring depth, spatial extent, and degree of strength of the liquefaction, which is essential for the reliable risk assessment of the sites. Three-dimensional imaging technique such as X-ray computed tomography (CT) is useful to detect the liquefaction-induced sand dykes embedded in the cores without fail. We applied medical X-ray CT to liquefied cores (depth 0 to 10 m) obtained from the Kanto region, Japan, where the 2011 off the Pacific coast of Tohoku Earthquake occurred (Nakashima and Komatsubara, 2016). Sand dykes intruding into silt layers can readily be detected by taking advantage of the significant difference in density and mineral composition between sand and silt. In contrast, sand dykes (i.e., disturbed sand) embedded in undisturbed sandy sediments with laminations were more difficult to detect due to little difference in density and composition between the disturbed and undisturbed sands. However, we successfully extracted the three-dimensional complex structures of sand dykes embedded in the sandy sediments (see attached figure) using a specific digital image segmentation technique (i.e., cellular automaton model) originally developed by Vezhnevets and Konouchine (2005). These results demonstrate that X-ray CT coupled with advanced digital image processing is a promising tool for the liquefaction identification in boring cores.

Reference:
Nakashima, Y. and Komatsubara, J. (2016) Seismically induced soft-sediment deformation structures revealed by X-ray computed tomography of boring cores. Tectonophysics, 683, 138-147 (open access). http://dx.doi.org/10.1016/j.tecto.2016.05.044



Three-dimensional images of sand dykes in a core (diameter, 64mm) obtained by X-ray CT (Nakashima and Komatsubara, 2016)

Development of MASW using Rayleigh wave and Love wave

Kazuya Sugita[1], *Yoshiya Oda[1]

1. Tokyo Metropolitan University

MASW estimates the S-wave velocity from measured dispersion curves of surface waves and in most applications, Rayleigh waves are used. We have developed inversion method using both Rayleigh wave and Love wave to improve the accuracy of MASW in this study.

Keywords: MASW, Rayleigh wave, Love wave

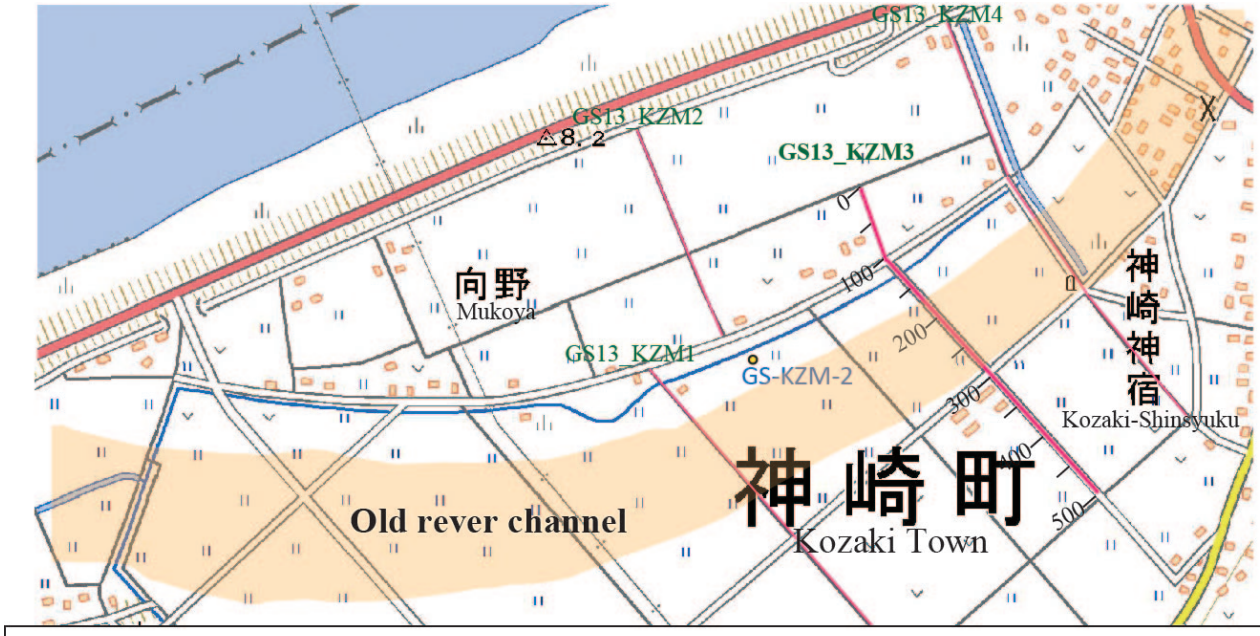
Surface wave surveys in the affected area of liquefaction which was generated by the 2011 off the Pacific coast of Tohoku Earthquake - A case study at Kozaki, Katori, Chiba -

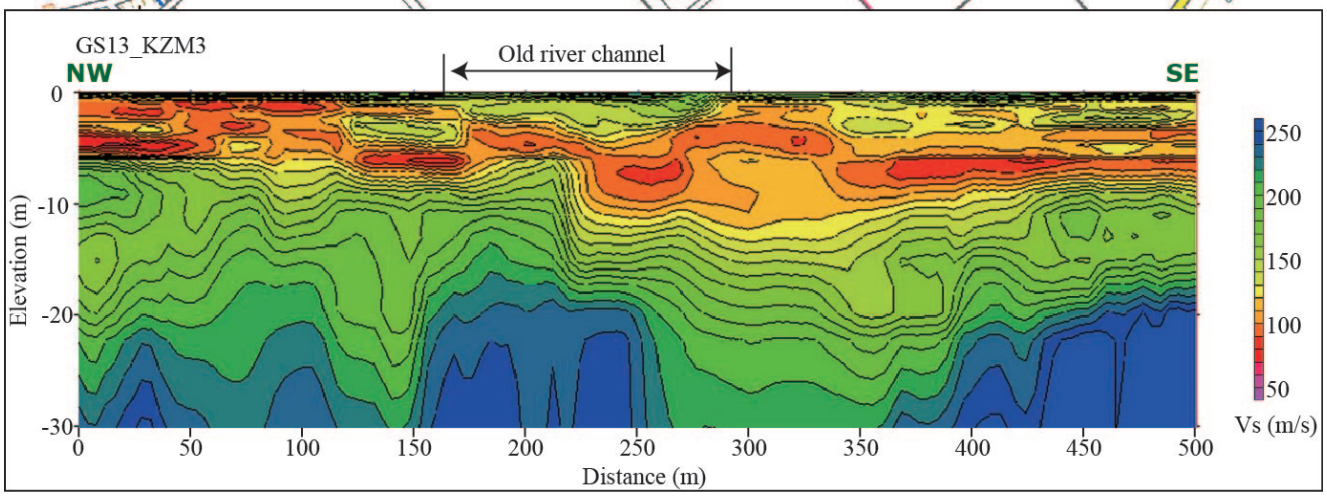
*Tishiyuki Yokota[1]

1. National Institute of Advanced Industrial Science and Technology

Serious liquefaction damage arose according to the 2011 off the Pacific coast of Tohoku Earthquake in the Tone River downstream region. Many of them occurred in the area where water zones were reclaimed until relatively recent years. In the survey area, Mukoya and the Kanzaki-Shinsyuku area, Kozaki, Katori, Chiba, the liquefaction was occurred in case of the 1987 Chibaken Toho Oki Earthquake (Kazaoka, 2003). Liquefaction damage was observed almost the same location in case of the 2011 off the Pacific coast of Tohoku Earthquake, the main reason of the repeated liquefaction damage at the identical location can be explained by the existence of the dredged-sand layer which filled up the old river channel of the Furu-Tone River which was reclaimed in 1963.
In this research, we carried out the surface wave surveys in Mukoya and Kozaki-Shinsyuku area along the four survey lines, GS13_KZM1 (500 m), GS13_KZM2 (300 m), GS13_KZM3 (500 m), and GS13_KZM4 (600 m). We used the land streamer for P-SV wave with a 1-m receiver interval for data acquisition. The central frequency of the receiver was 4.5 Hz, shot-point interval was 2 m, and the maximum offset was 96 m. The acquired data were sorted into the common mid-point gathers as the manner of Hayashi (2001) (the CMPCC method), and processed with the quasi-two-dimensional analysis with assuming the one-dimensional structure (horizontal layered model) beneath each CMP locations. Since the feature of inverse-dispersion nature was observed in the acquired data, both fundamental and higher modes were used in the inversion procedure.
The result of survey-line GS13_KZM3 is shown among the obtained S-wave velocity structures. It is the survey line which crosses the old river channel of the Furu-Tone River, distance of about 100-300 m corresponds to the old river channel portion. Within the 0-100 m interval, the low velocity zone of Vs value is less than 100 m/s can be observed in the shallower portion. We can interpret the low velocity layer as silty layer, and the interpretation agrees well with drilling results. In the section of the old river channel along the survey line GS13_KZM3, we can see the syncline structure of Vs values about 140 to 170 m/s, and another syncline structure of less than 100 m/s can be seen under it. The most probable interpretation of these structures is the existence of the old river channel which were filled with dredged-sand. As considering the interval from the view point of liquefaction, since the silty layer locates beneath the dredge sand layer with homogeneous particle diameter, the water level in the sand layer tends to be kept high, moreover, the shape of the layer tends to enlarge the ground motion when the earthquake happens. From these, liquefaction probably happen in this domain when another big earthquake occurs. In the interval of about 300-500 m, we can see relatively flat alternation of strata with some layers.

Keywords: surface wave survey, the 2011 off the Pacific Coast of Tohoku Earthquake, liquefaction, old river channel





Attempt to Self-potential in shallow groundwater area, Akita prefecture

*Koushou Tanaka[1], Kazuhiro Amita[2], Kyosuke Onishi[3]

1. Graduate School of International Resource Sciences Akita University, 2. Reserch Center for Engineering Science, Akita University, 3. Public Works Reserch Institute

A study is one of the geophysical explorations. It has been used in the volcanic and geothermal areas in order to investigate hydrothermal water convections. The relationship between SP and groundwater flow still is not well studied. It is important to clarify the groundwater flow. It is because the use in groundwater management.
In this study, SP survey was carried out at the shallow groundwater field. And, we examined whether it is possible to observe what kind of SP. It was investigated in a place where there is a lot of groundwater level data and gradient data.
We have selected Rokugo alluvial fan in Akita prefecture, is because of the groundwater level data has been recorded. Rokugo alluvial fan has an area of about 4km from east to west, and approximately 5km from north to south. Its area is 14km². The study was carried out in September-November, 2015.
From the observation result, it was possible to find SP decreases section as the altitude increases. In the case of Rokugo alluvial fan, the topographic effect is -1.0 ~ -3.7mV/m.

Keywords: Shallow ground water, Self-Potential, Streaming potential

Survey for tree root system GPR by synchronized with self-tracking total station

*Kunio Aoike[1], Kazunori Takahashi[1], Yayoi Ishizawa[1], Ishizawa Nobuaki[1]

1. Oyo corporation

A non-destructive inspection for imaging the exact root system of trees under the ground surface is important to assess the healthiness of trees or to evaluate the risk of collapse. The authors applied a GPR (Ground Penetrating Radar) survey to image the distribution of lateral root system in detail. The system used in the surveys was a cart type GPR that is able to synchronize GPR traces with accurate antenna positions obtained by a self-tracking total station using an active target mounted on the GPR antenna. Since the tracking rate of our total station is 2.5 times per a second, it has a nonnegligible delay to determine the position relative to the rate of GPR scanning. The delay causes positioning error that depends on the operation speed. We conducted an experiment to determine the relation between the operation speed and the error and the accuracy was improved by correcting the error using the relation. We applied the system to trees in three different surface conditions: The first case is a Quercus planted in a loam layer. The second case is a Platanus. The ground surface around the tree is paved and layer under pavement is a natural gravel layer. The last case is a Japanese black pine planted in sand near seashore. In all the cases, we could successfully image the detailed root distribution in the near-surface layer, and in the case of the Japanese black pine the horizontal root distribution was identified up to the depth of 1m.

Keywords: GPR, Total station, Root system

Matching locations of survey lines and common reflection points between multi-channel GPR records

*Kyosuke Onishi[1], Takanori Ogahara[1], Hiroshi Kisanuki[1], Tomio INAZAKI[1]

1. Public Works Research Institute

Recent multi-channel ground-penetrating radar (GPR) provides high volume of survey data in short time. Also, high accurate GNSS measurement can be easily used and the combination of GPR and GNSS provides many repeated records in the similar locations. However, repeatedly acquired GPR records cannot be acquired at the exactly same locations and must be surveyed at the slightly different locations. Positioning accuracy of RTK-GNSS is not enough to set survey locations or detect relative survey positions with between two different surveys. On the other hand, repeatedly scanned survey records using multi-channel GPR in a similar survey line have large potential to improve the signal to noise ratios of survey records and detect underground events. Matching locations of survey lines and common reflection points between repeatedly surveyed multi-channel GPR records becomes an important technique for future GPR processing. We will discuss methods of matching two or more different survey records of multi-channel GPR and show results matched with relative positions of records which are actually acquired on paved roads. A set of multi-scanned survey records has high dense information for space and many CMP records which can be useful for making a velocity distribution map.

Keywords: 3D, CMP, velocity analysis

Multi-offset reflection records from point scatterers and velocity analysis

*Kyosuke Onishi[1], Hiroshi Kisanuki[1], Takanori Ogahara[1], Tomio INAZAKI[1]

1. Public Works Research Institute

Ground-penetrating radar records include a lot of reflection events from point scatterers. Soil and ground in near surface includes many stones which are smaller than a typical wave length of propagated electro-magnetic waves of ground-penetrating radar. This relationship is far difference from standard reflection seismic records which include mainly reflection events from continuous layer boundaries. Records of ground-penetrating radar show a lot of diffraction patterns from small scatterers which are frequently main survey targets of the ground-penetrating radar surveys. When applying migration processing for the ground-penetrating radar records, the events from point scatterers sometimes change difficult to be detected in background waves. Therefore, migration processing is frequently skipped in the processing of ground-penetrating radar. The other characteristic issue due to point scatterers in ground-penetrating radar survey is much noise in a semblance panel for velocity analysis. Point scatterers are not normally located just below the survey line. A point scatterer located with the same length of propagation path but not located just below the survey line must be located in a shallower zone from a point scatterer located just below the survey line. Different depth zones frequently have different dielectric constant and the reflection event from a point scatterer not located just below the survey line, which is frequently located in a different velocity zone, makes a strong error event in the semblance panel. We want to discuss this issue and try to avoid it using 3D multi-offset records.

Keywords: GPR, velocity analysis, scatterer

