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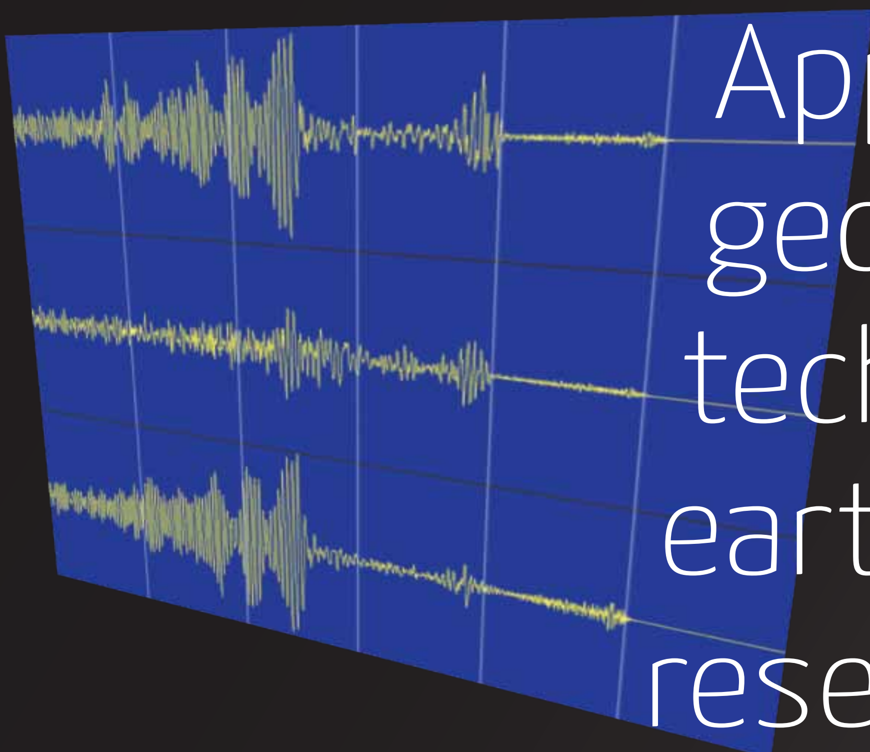

Application of geophysical techniques for earthquake research

In this issue . . .

- Call for Paper: Special Issue of JEEG
- Tucson Hosts SAGEEP 2012
- SERDP AND ESTCP Symposium
- The EEGS / Geonics Early Career Award

. . . and more!

Thermal Integrity Profiler

On the Cover

This issue features the application of geophysical techniques for earthquake research.

What We Want From You

The ***FastTIMES*** editorial team welcomes contributions of any subject touching upon geophysics. The theme for our next issue will be the development and application of electrical resistivity techniques for near surface investigations. ***FastTIMES*** also accepts photographs and brief non-commercial descriptions of new instruments with possible environmental or engineering applications, news from geophysical or earth-science societies, conference notices, and brief reports from recent conferences. Please submit your items to a member of the ***FastTIMES*** editorial team by November 21, 2011 to ensure inclusion in the next issue. We look forward to seeing your work in our pages.

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FastTIMES

FastTIMES (ISSN 1943-6505) is published by the Environmental and Engineering Geophysical Society (EEGS). It is available electronically (as a pdf document) from the EEGS website (www.eegs.org).

About EEGS

The Environmental and Engineering Geophysical Society (EEGS) is an applied scientific organization founded in 1992. Our mission:

"To promote the science of geophysics especially as it is applied to environmental and engineering problems; to foster common scientific interests of geophysicists and their colleagues in other related sciences and engineering; to maintain a high professional standing among its members; and to promote fellowship and cooperation among persons interested in the science."

We strive to accomplish our mission in many ways, including (1) holding the annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (**SAGEEP**); (2) publishing the ***Journal of Environmental & Engineering Geophysics (JEEG)***, a peer-reviewed journal devoted to near-surface geophysics; (3) publishing ***FastTIMES***, a magazine for the near-surface community, and (4) maintaining relationships with other professional societies relevant to near-surface geophysics.

Joining EEGS

EEGS welcomes membership applications from individuals (including students) and businesses. Annual dues are currently $90 for an individual membership, $50 for a retired member $20 for a student membership, $50 developing world membership, and $650 to $4000 for various levels of corporate membership. All membership categories include free online access to JEEG. The membership application is available at the back of this issue, or online at www.eegs.org. See the back page for more information.

FastTIMES Submissions

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FastTIMES is published electronically four times a year. Please send articles to any member of the editorial team by November 21, 2011. Advertisements are due to Jackie Jacoby by November 21, 2011.

Calendar

*Please send event listings, corrections or omitted events to any member of the **FastTIMES** editorial team.*

2011

September 12–14	Near Surface 2011: 17th European Meeting of Environmental and Engineering Geophysics, Leicester, England
October 9–12	GSA 2011 Annual Meeting: Archean to Anthropocene: The past is the key to the future, Minneapolis, Minnesota
November 20–23	10th SEGJ International Symposium: features the interdisciplinary integration of geosciences for better understanding and modeling of invisible underground structures and processes, Kyoto, Japan
November 21	Deadline for submission of articles, advertisements, and contributions to the December issue of *FastTIMES*
Nov 29 – Dec 1	SERDP and ESTCP Partners in Environmental Technology Technical Symposium & Workshop “Meeting DoD’s Environmental Challenges”, Washington, D.C.
December 5-9	2011 AGU Fall Meeting. San Francisco, CA

2012

January 15–17	International Conference on Earth Sciences and Engineering: brings together scientists, engineers, and students to share their experiences and research results about all aspects of Earth Sciences and Engineering, Zurich, Switzerland
February 21	Deadline for submission of articles, advertisements, and contributions to the March issue of *FastTIMES*
February 26–29	22nd ASEG: the conference theme ‘Unearthing New Layers‘ recognises that transformational change in our industry can still occur, Melbourne, Australia
March 25-29	25th Anniversary Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) “Making Waves: Geophysical Innovations for a Thirsty World”, Tucson, AZ
May 21	Deadline for submission of articles, advertisements, and contributions to the June issue of *FastTIMES*
June 15~18	5th International Conference on Environmental and Engineering Geophysics, Changsha, China

President's Message: Be a Proud Member!

Mark Dunscomb, President (mdunscomb@schnabel-eng.com)

"So what do you do?" "I'm a geophysicist." "Oh, that's interesting. Uh, so what does a geophysicist do?"

Let's face it, near-surface geophysicists are not like coffee shops. You don't find them on nearly every corner. However, that in no way is reflective of the near-surface geophysicist's importance to society. Looking into the future, there are a few things that are certain: urban areas will grow, infrastructure continues to get old, and sustainable potable water sources become increasingly critical. These three points impact all of us, whatever area of geophysics you practice in, and geophysicists should be involved with the solutions. What does that mean for you and EEGS?

Given our positive future and the enormous rate of change in technology, it's important to stay connected. EEGS is the only geophysical society in North America that focuses solely on the near-surface. We represent a diverse group (including practitioners, researchers and professors, and instrument developers and manufacturers, not to mention all the applications that we delve in) and yet we have common goals and collaborate to enhance the field of near-surface geophysics. We need you to make the society even better. Here are my top three reasons for being a member.

Relationships: Call it networking, friendship, cooperative business arrangements, whatever the name this is one thing you don't generally learn enough about in school. Relationships in your chosen field broaden your perspective, create opportunities for career development, and help you understand your competitors. Its importance can't be stated strongly enough.

Broaden your knowledge: EEGS brings together the key components to expand your understanding of the latest in near-surface technologies. I can speak personally to the fact that I've called many people in the society and have been called many times to exchange information on everything from understanding the physics of developing approaches to how to implement certain data collection techniques. Membership also supports the Journal of Environmental and Engineering Geophysics (JEEG) and information or access to other related publications. That's not to mention SAGEEP, the EEGS annual meeting, where you can learn from others and enhance your own professional visibility by presenting your ideas and experience.

Outreach: It's important to near-surface geophysics as a whole to reach out to students, related societies internationally, and organizations of professionals and researchers that have common interests. According to research conducted by the American Geological Institute (of which everyone in EEGS is automatically also a member), there is a potential for a net demand for about 150,000 geoscientists, including geophysicists, by the year 2021. How will the word get out if not from us? We need to accurately explain the advantages to incorporating geophysical technologies in investigations, evaluations, and monitoring the near-surface.

But, outreach means more than that; it also includes using our talents and knowledge to aid those who could benefit from them. EEGS has teamed, via the EEGS Foundation, with Geoscientists without Borders to assist with their pursuit of humanitarian applications around the world.

So get involved, take charge of your professional development and help your community, be proud of your EEGS membership, and if you are not a member yet, join us.

EEGS Foundation makes great strides in its first years.

Since the launch of the EEGS Foundation, there are numerous accomplishments for which we can all be proud: Establishing and organizing a structure that serves the needs of EEGS; underwriting the legal process, achieving tax-exempt status; and soliciting and receiving support for SAGEEP. In addition, the Foundation helped underwrite the SAGEEP conference held this spring in Keystone.

These are only a few of the tangible results your donations to the Foundation have enabled. We would therefore like to recognize and gratefully thank the following individuals and companies for their generous contributions:

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Arumugam, Devendran
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Harold Mooney Award

Our own Jonathan E. Nyquist, Professor and Week's Chair in Environmental Geology at Temple University is the 2011 winner of the Harold Mooney award. The award was presented by NSG President Klaus Holliger at the Near Surface Geophysics Section reception held at the 2011 SEG annual meeting in San Antonio, TX. The Mooney award is given "in recognition of long-term, tireless, and enthusiastic support of the near-surface geophysics community through education, outreach efforts, professional service, or development of opportunities with other professional disciplines that employ geophysics."

Congratulations!

Renew your EEGS Membership for 2012

Be sure to renew your EEGS membership for 2012! In addition to the more tangible member benefits (including the option of receiving a print or electronic subscription to ***JEEG***, ***FastTIMES*** delivered to your email box quarterly, discounts on EEGS publications and SAGEEP registration, and benefits from associated societies), your dues help support EEGS's major initiatives such as producing our annual meeting (SAGEEP), publishing ***JEEG***, making our publications available electronically, expanding the awareness of near-surface geophysics outside our discipline, and enhancing our web site to enable desired capabilities such as membership services, publication ordering, and search and delivery of SAGEEP papers. New this year is an opportunity to donate to the EEGS Foundation during the renewal process. Members can renew by mail, fax, or online at *www.eegs.org*.

Sponsorship Opportunities

There are always sponsorship opportunities available for government agencies, corporations, and individuals who wish to help support EEGS's activities. Specific opportunities include development and maintenance of an online system for accessing SAGEEP papers from the EEGS web site and support for the 2012 SAGEEP conference to be held in Tucson, Arizona. Contact Mark Dunscomb (*mdunscomb@schnabel-eng.com*) for more information.

EEGS Announces Changes in Membership

It's time to renew your membership in EEGS – we've added options and increased benefits!

EEGS members, if you have not already received a call to renew your membership, you will – soon! There are a couple of changes of which you should be aware before renewing or joining.

Benefits - EEGS has worked hard to increase benefits without passing along big increase in dues. As a member, you receive a Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) registration discount big enough to cover your dues. You also receive the Journal of Environmental and Engineering Geophysics (JEEG), the *FastTIMES* newsletter, and full access to the EEGS research collection, which includes online access to all back issues of JEEG, SAGEEP proceedings, and SEG extended abstracts. You get all of this for less than what many societies charge for their journals alone.

Dues Changes - EEGS has worked hard to hold the line against dues increases resulting from inflation and higher costs. Instead, EEGS leadership sought ways to offer yesterday's rates in today's tough economic climate. Therefore, you can continue your EEGS membership without any rate increase if you opt to receive the JEEG in its electronic format, rather than a printed, mailed copy. Of course, you can continue to receive the printed JEEG if you prefer. The new rate for this membership category is modestly higher reflecting the higher production and mailing costs. A most exciting addition to EEGS membership choices is the new discounted rate for members from countries in the developing world. A growing membership is essential to our society's future, so EEGS is urging those of you doing business in these countries to please encourage those you meet to take advantage of this discounted membership category, which includes full access to the EEGS research collection. And, EEGS is pleased to announce the formation of a Retired category in response to members' requests.

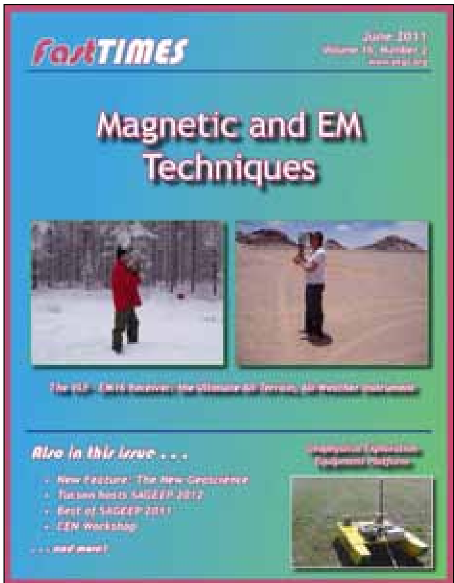
Descriptions of all the new membership options are outlined on EEGS' web site (www.eegs.org) in the membership section.

Renew Online - Last year, many of you took advantage of our new online membership renewal (or joining EEGS) option. It is quick and easy, taking only a few moments of your time. Online membership and renewal application form is available at www.eegs.org (click on Membership and then on Online Member Application / Renewal).

EEGS Foundation - EEGS launched a non-profit foundation (www.eegsfoundation.org) that we hope will enable our society to promote near-surface geophysics to other professionals, develop educational materials, fund more student activities, and meet the increasing demand for EEGS programs while lessening our dependence on membership dues. A call for donations (tax deductible*) to this charitable organization is now included with your renewal materials and can be found on the online Member Resources page of EEGS' web site (www.eegs.org/pdf_files/eegs_foundation.pdf).

Member get a Member - Finally, since the best way to keep dues low without sacrificing benefits is to increase membership, please make it your New Year's resolution to recruit at least one new EEGS member. If every current member recruited even one new member to EEGS, we could actually consider lowering dues next year!

*As always, seek professional advice when claiming deductions on your tax return.



From the FastTIMES Editorial Team

FastTIMES is distributed as an electronic document (pdf) to all EEGS members, sent by web link to several related professional societies, and is available to all for download from the EEGS web site at http://www.eegs.org/Publications/FASTTIMES/LatestIssue.aspx. The most recent issue (June 2011, cover image at left) has been downloaded more than 10,000 times as of September 2011, and past issues of ***FastTIMES*** continually rank among the top downloads from the EEGS web site. Your articles, advertisements, and announcements receive a wide audience, both within and outside the geophysics community.

To keep the content of ***FastTIMES*** fresh, the editorial team strongly encourages submissions from researchers, instrument makers, software designers, practitioners, researchers, and consumers of geophysics—in short, everyone with an interest in near-surface geophysics, whether you are an EEGS member or not. We welcome short research articles or descriptions of geophysical successes and challenges, summaries of recent conferences, notices of upcoming events, descriptions of new hardware or software developments, professional opportunities, problems needing solutions, and advertisements for hardware, software, or staff positions.

The ***FastTIMES*** presence on the EEGS web site has been redesigned. At www.eegs.org/fasttimes, you'll now find calls for articles, author guidelines, current and past issues, and advertising information.

The JEEG Page

*The **Journal of Environmental & Engineering Geophysics (JEEG)**, published four times each year, is the EEGS peer-reviewed and Science Citation Index (SCI®)-listed journal dedicated to near-surface geophysics. It is available in print by subscription, and is one of a select group of journals available through GeoScienceWorld (www.geoscienceworld.org). **JEEG** is one of the major benefits of an EEGS membership. Information regarding preparing and submitting **JEEG** articles is available at http://jeeg.allentrack.net.*

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The ***Journal of Environmental and Engineering Geophysics (JEEG)*** is the flagship publication of the Environmental and Engineering Geophysical Society (EEGS). All topics related to geophysics are viable candidates for publication in ***JEEG***, although its primary emphasis is on the theory and application of geophysical techniques for environmental, engineering, and mining applications. There is no page limit, and no page charges for the first ten journal pages of an article. The review process is relatively quick; articles are often published within a year of submission. Articles published in ***JEEG*** are available electronically through GeoScienceWorld and the SEG's Digital Library in the EEGS Research Collection. Manuscripts can be submitted online at *www.eegs.org/jeeg/index.html*.

EAGE's Near Surface Geophysics Journal, August 2011

*As a courtesy to the European Association of Geoscientists and Engineers (EAGE) and the readers of **FastTIMES**, we reproduce the table of contents from the August issue of EAGE's **Near Surface Geophysics** journal.*

EAGE
EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS

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Volume 9 · Number 4 · August 2011

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Corrigendum

www.nearsurfacegeophysics.org

FastTIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, soil science, hydrology, archaeology, and astronomy. This issue of FastTIMES presents selected articles from JEEG and SAGEEP proceedings.

SEISMIC AND GEOTECHNICAL SITE CHARACTERIZATIONS AT FOUR EARTHQUAKE STRONG MOTION SITES IN WASHINGTON STATE

Recep Cakir, Geol.&Earth Resources, Washington State Dept. of Natural Resources, Olympia, WA
Timothy J. Walsh, Geol.&Earth Resources, Washington State Dept. of Natural Resources, Olympia, WA
Trevor Contreras, Geol.&Earth Resources, Washington State Dept. of Natural Resources, Olympia, WA

Abstract

As part of on going program for generating maps addressing geologic site effects in Washington, the Washington State Department of Natural Resources (DNR), Division of Geology and Earth Resources (DGER) drilled 30-meter-deep geotechnical boreholes at four strong-motion sites operated by the Pacific Northwest Seismic Network (PNSN). Invasive (soil sampling, Standard Penetration Test (SPT) and downhole seismic) and noninvasive (Multichannel Analysis of Surface Waves, (MASW)) methods were used to determine shear-wave velocity profiles, specifically for the top 100 feet of soil column, at each of these strong motion sites.

The boreholes were logged for visual soil classification and SPTs, and selected soil samples were tested in the laboratory to obtain plasticity and gradation values. In addition, S-and P-waves generated at the surface were received by a 3-component geophone placed at 1-m intervals in each borehole. Then the borehole sites were later surveyed by using MASW method to estimate the Vs profiles at each borehole site. The MASW survey shows a very good correlation with the downhole S-velocity profiles. SPT blow counts are consistent with soil conditions in the Puget Sound area. Site classes E, D-E, D, C-D and C, as described in the International Building Codes (IBC 2006), were determined by using average shear-wave velocities and SPT blow count values to 30 meters (~100 feet) of soil column of the four boreholes.

An updateable geospatial database incorporating shear-wave data and velocities, borehole geotechnical information (soil samples and their laboratory tests, SPT blow counts, etc.) will be generated and periodically updated. This database will directly be available through the DGER‘s interactive mapping service for end users such as federal and local government agencies, urban planning and emergency response groups and seismic networks, such as PNSN.

Introduction

Local soil and geologic site variations during moderate to large earthquakes have major impact on buildings, lifelines, bridges and other critical structures such as dams and power plants. Also, local soil/geological site variations directly affect on the earthquake signals received by the seismograph or seismographs network. Shallow site effect must be known to determine 1) a more reliable earthquake magnitude, 2) a better local site classification which is important for the building codes, and 3) liquefaction susceptibilities. Therefore, acquiring shear wave velocity data either by surface seismic surveys (noninvasive) or by downhole seismic surveys (invasive) is a critical step. To better determine the seismic site effects at strong motion station sites, the Washington State Department of Natural Resources, Division of Geology and Earth Resources (DGER) drilled 100-feet deep geotechnical boreholes at four given locations (Figure 1) (Bodin, 2007). These strong motion sites have been operated by the Pacific Northwest Seismic Network (PNSN). Among these four station sites DNR is scheduled to be operated after its installation sometime in 2008.

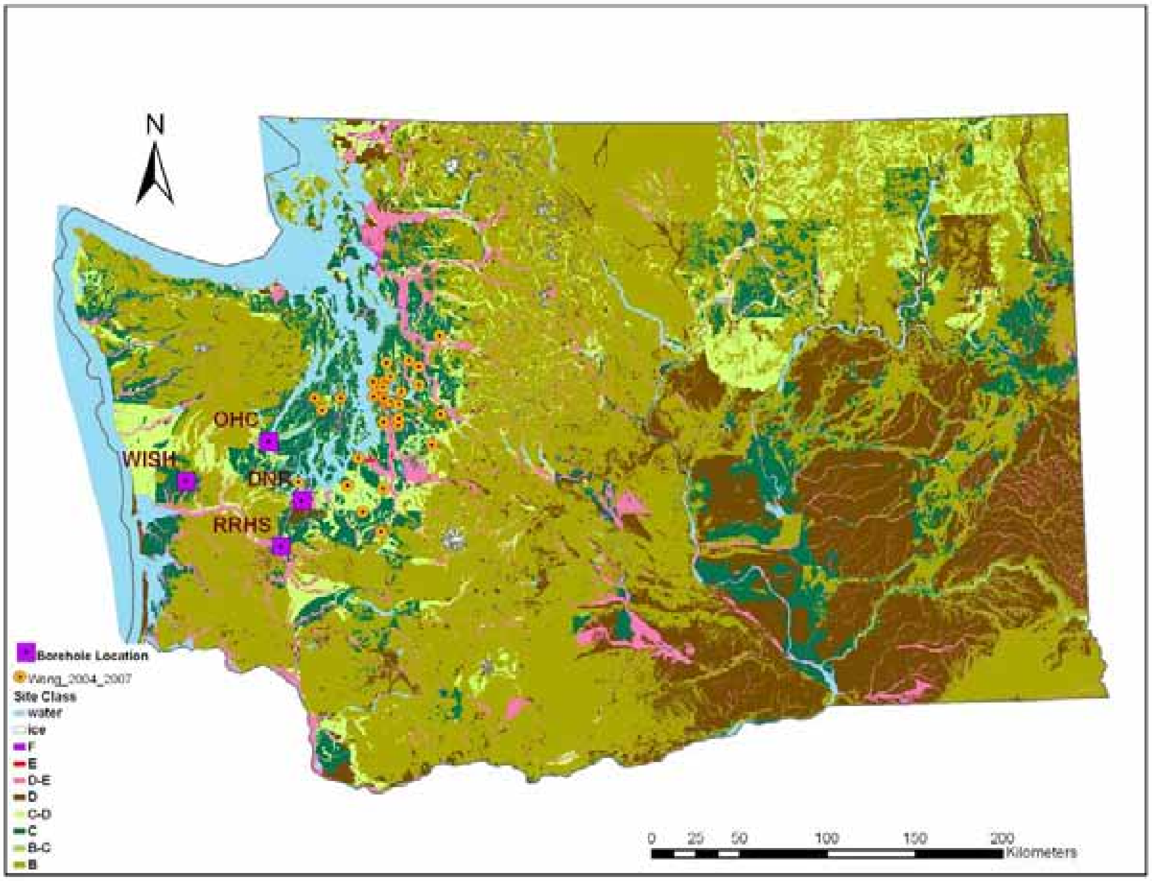

Figure 1: Recently drilled four earthquake strong motion recording sites (squares); Hood Canal (OHC), Wishkah (WISH), Rochester (RRHS) and Washington State Department of Natural Resources-Olympia (DNR) are shown along with previous site characterization locations investigated by Wong and Stokoe (2004) (circles).

Invasive and Non Invasive Methods and Data

DNR-Division of Geology and Earth Resources drilled 30-meter-deep geotechnical boreholes at four strong-motion sites operated by the Pacific Northwest Seismic Network (PNSN). Invasive (Standard Penetration Test (SPT) and downhole seismic) and noninvasive (Multichannel Analysis of Surface Waves (MASW) combined with Microtremor Array Measurement (MAM)) methods were then used to determine shear-wave velocity profiles with respect to depth at each strong motion site. In each borehole SPTs were completed by counting the blows per foot. Also, soil samples (disturbed) taken during the SPTs were visually inspected and few selected samples were later tested in the laboratory to determine plasticity and gradation characteristics.

After the SPTs and soil samplings were completed, each 30-m borehole was cased with 2-inch PVC and backfilled with cement. For each site downhole seismic survey was then conducted by generating shear-wave source received by a 3-component geophone system. A nine foot long 6x10" wood beam with 1.5" thick protective steel end caps was coupled to the ground by parking the front two wheel of a field vehicle on top of the beam. The wood beam was placed on the ground at 3 meters from the boring. A 3-component borehole geophone package manufactured by the Oyo Corporation was lowered and fixed for each depth by coupling to the wall of the casing. An inflating a pneumatic bladder was used for coupling. Then we generated horizontally polarized shear waves by striking with a 12 lb. sledge hammer on each end of the wood beam. These shear wave energy signals were received by the 3-component geophone at every 1 meter in 30-meter (~100 feet) borehole and recorded on three designated channels of a 24-channel GEODE manufactured by Geometrics Inc.

We later surveyed the sites by using the MASW and the MAM noninvasive methods to test how these surface-wave methods correlate with invasive downhole seismic method for obtaining the shear-wave velocity profiles, specifically in top 100 feet of the soil column. Our plan is to use the MASW method extensively for future site characterizations. This method has been extensively studied and tested for various shallow earth problems by the Kansas Geological Survey (KGS) (Miller et al., 1999; Park et al., 1999; Xia et al., 2000). We strongly encourage readers to visit the KGS website (http://www.kgs.ku.edu/Geophysics/pubs.html) for more references about the method. A 12 lb sledge hammer source and 4.5-Hz vertical geophones with 3 meter interval were used to generate and receive surface (Rayleigh) waves recorded on a 24-channel GEODE. Time sampling, record length and shot interval for MASW acquisition and geometry parameters were selected as 0.125 millisecond, 1 second, and 3 meters, respectively. Dispersion curves (phase velocity vs. frequency) and their inverted shear-wave velocity profiles were obtained by using software analyzing seismic surface-waves (SeismicImager/SW, 2006).

After completion of the downhole seismic survey, arrival times of the shear waves to horizontal component of the 3-component geophone were determined by visual inspection of the pair waveforms generated by striking on each end of the wood beam. Waveform pairs having approximately 180 degree phase difference were identified as shear-wave arrivals on transverse direction (S_H). In addition to first breaks arrival times, first peak and first maximum arrival times of the pairs were determined to reduce uncertainty in picking the first break arrival times. These measured arrival times were then corrected to match hypothetical vertically-travelling waves assuming straight-line ray path. For each depth these corrected arrival times were then used to calculate interval shear-wave velocities.

We compared SPT values with the downhole seismic velocities and shear-wave velocity averaged to 100 feet depth (Vs100) and assigned site classes based on NEHRP classification schemes (IBC 2006). We finally summarized the results in comparison with MASW shear-wave velocities.

Results

DNR (Department of Natural Resources) Site

DNR Station site is approximately 100 meters north of the Department of Natural Resources building and scheduled to be used as a strong motion site, after installation is completed by the PNSN in 2008. Figure 2 shows site class map (Palmer et al., 2004) and scheduled DNR strong motion site.

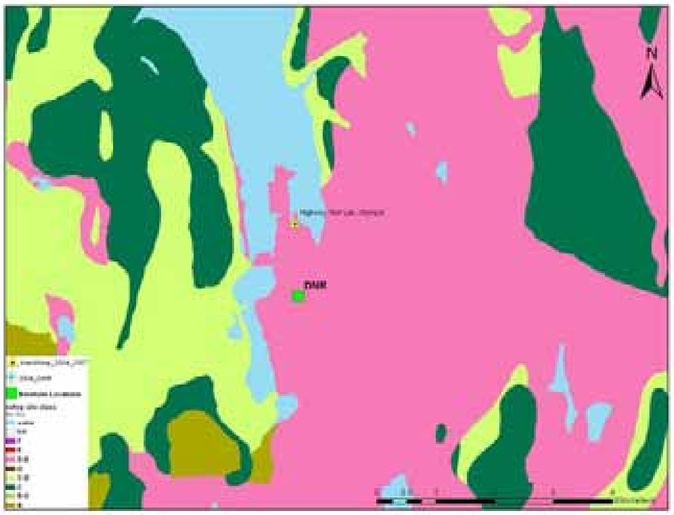

Figure 2: DNR site is underlain by NEHRP site class map (Palmer et al, 2004) for WA. The site was previously determined as NEHRP class D-E.

After carefully conducting downhole seismic survey, arrival times were manually picked based on first breaks (fb), first peaks (fp) and first maximums (fm) of the shear waves. Then these arrival times geometrically corrected and interval velocities were calculated. Figure 3 shows shear-wave velocity profiles, combined with SPT-N blow counts, determined using downhole seismic data. Both data sets were acquired from the 100-feet (~30 meters) deep borehole.

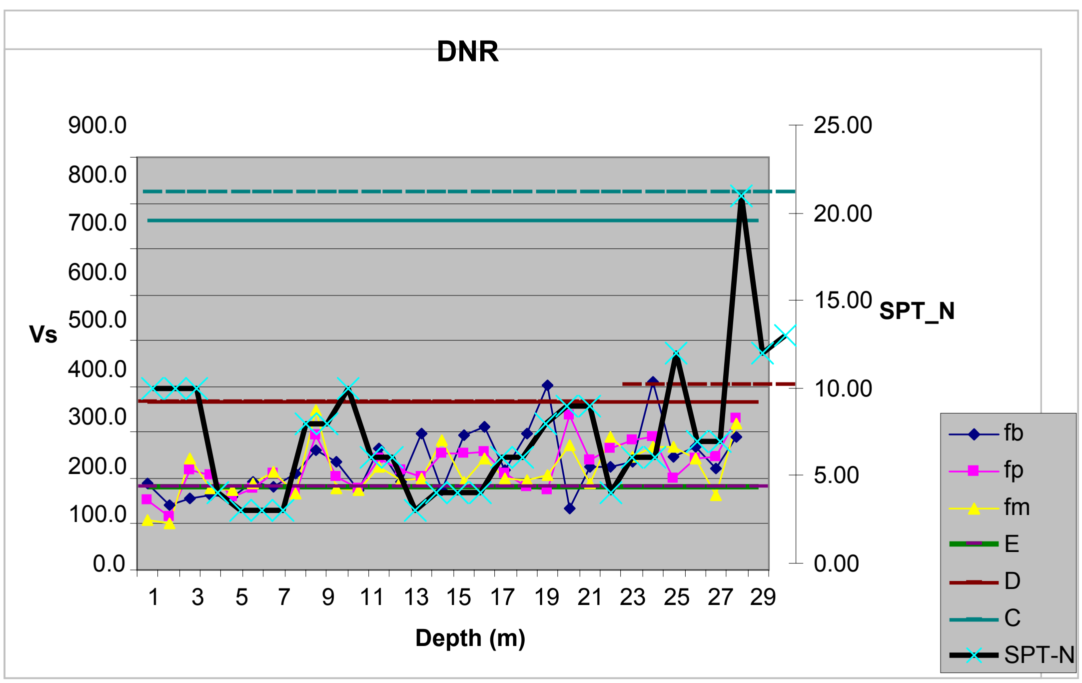

Figure 3: Velocity and SPT-N (blow counts) profile for the DNR site. Symbols fb, fp and fm represents first break, first peak and first maximum, respectively, arrival times of the horizontally polarized shear waves. E, D and C lines are marked to identify NEHRP site class boundaries given in the IBC 2006.

Results from calculation of the NEHRP average shear-wave velocities for top 100 feet depth (Vs100) using fb, fp, fm and SPT-N data show that site class is D-E. Also, MASW results shown in Figure 4 give Vs average value which is in a good agreement with downhole seismic and SPT-N results. Table 1 summarizes all 100 feet (30 meter) NEHRP averaged values and site classes.

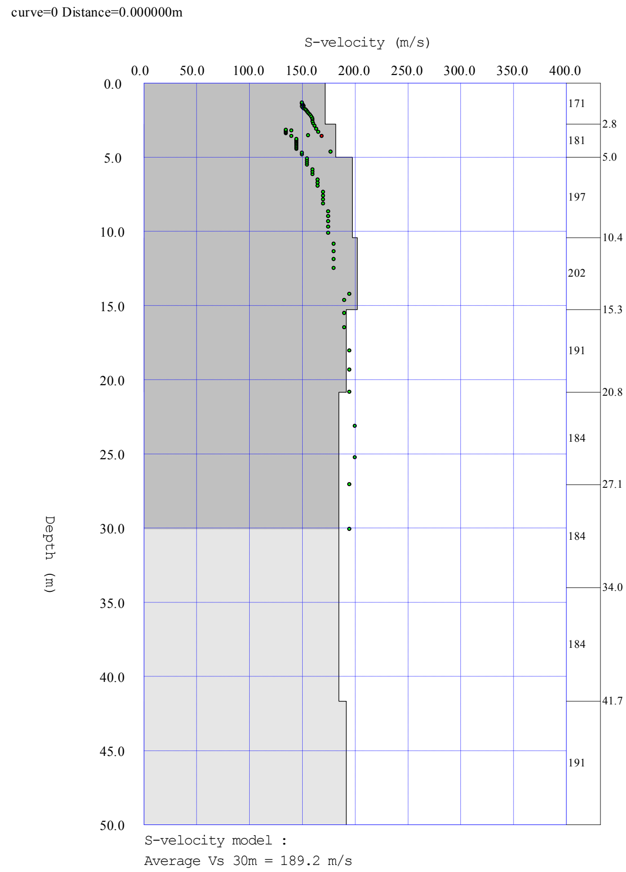

Figure 4: Vs velocity profile determined from the MASW analysis. This profile gives 620 ft/sec for the NEHRP average velocity (Vs100) of top 100-feet soil column.

Table 1: Calculated averaged Vs100 and SPT-N values and the corresponding NEHRP site classes (IBC 2006). Vs100 and N100 are averaged shear-wave velocities and SPT blow counts to top 100 ft (~30 meter) of soil column, respectively.

Values for DNR		NEHRP Site Class
Vs100_fb (ft/sec)	**726**	**D**
Vs100_fp (ft/sec)	**717**	**D**
Vs100_fm (ft/sec)	**673**	**D**
N100 (blow counts)	**6**	**E**
Vs100_MASW (ft/sec)	**621**	**D**
Interpreted NEHRP site class based on listed values above = D-E and D		

RRHS (Rochester) Site

RRHS is currently operating PNSN strong motion site. It is located in the Rochester High School (Figure 5).

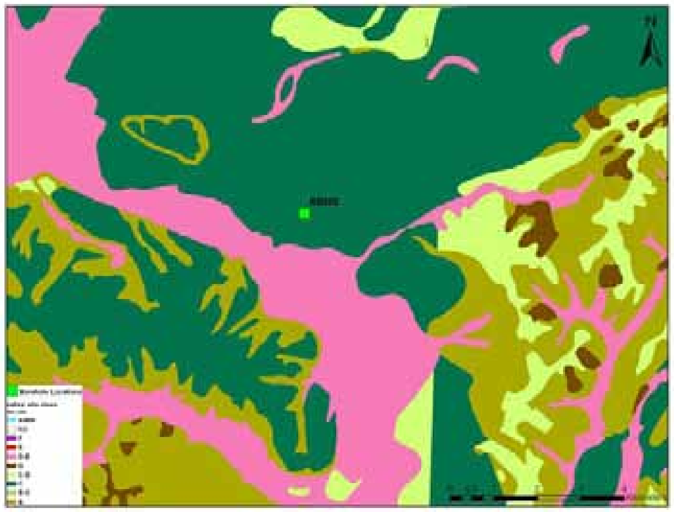

Figure 5: RRHS site (green square) is underlain by NEHRP site class map (Palmer et al, 2004) for WA. The site was previously determined as NEHRP class C (very dense soil and soft rock).

Figure 6 shows shear-wave velocity profiles, combined with SPT-N blow counts, determined by processing the downhole shear-wave data. Both data sets were acquired from the 100-feet (~30 meters) deep borehole. Results from calculation of the NEHRP average shear-wave velocities for top 100 feet depth (Vs100) using fb, fp, fm and SPT-N data show that site class can be rated as C. Also, MASW results shown in Figure 7 give average Vs value which is in a good agreement with downhole seismic and SPT-N results. Table 2 summarizes all 100 feet (30 meter) NEHRP averaged values and site classes for OHC site.

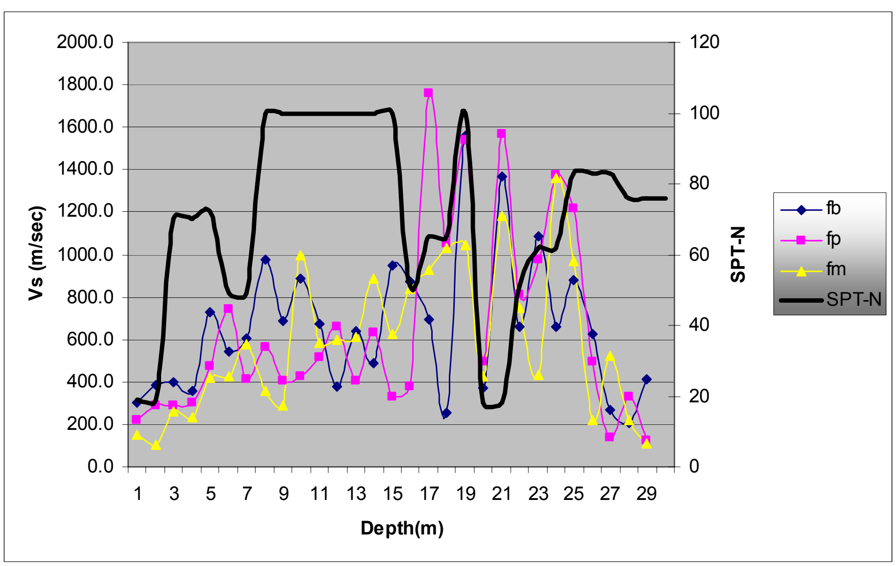

Figure 6: Velocity and SPT-N (blow counts) profiles for the RRHS (Rochester) site. Symbols fb, fp and fm represents first break, first peak and first maximum, respectively, arrival times of the shear waves vibrating transversely to the source-receiver (radial) direction.

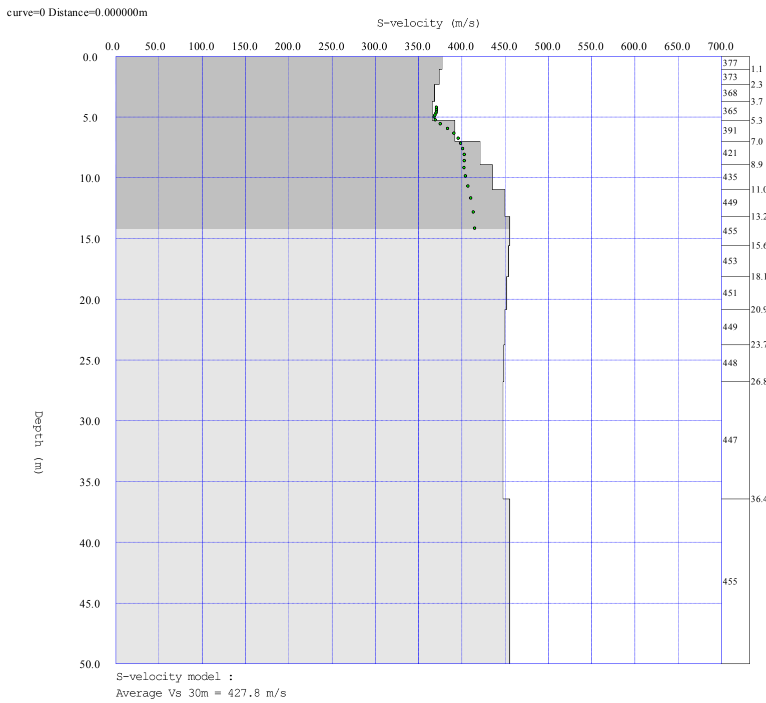

Figure 7: Shear velocity profile obtained from MASW analysis. This velocity profile gives averaged Vs100 = 1403 ft/sec.

Table 2: Calculated averaged Vs100 and SPT-N values and the corresponding NEHRP site classes (IBC 2006). Vs100 and N100 are averaged shear-wave velocities and SPT blow counts to top 100 ft (~30 meter) of soil column, respectively.

Values for RRHS		**NEHRP Site Class**
Vs100_fb (ft/sec)	**1695**	**C**
Vs100_fp (ft/sec)	**1288**	**C**
Vs100_fm (ft/sec)	**1137**	**D**
N100 (blow counts)	**53**	**C**
Vs100_MASW (ft/sec)	**1403**	**C**
Interpreted NEHRP site class based on listed values above = C		

OHC (Hood Canal) Site

Figure 8 shows site class map (Palmer et al., 2004) and the OHC strong motion site.

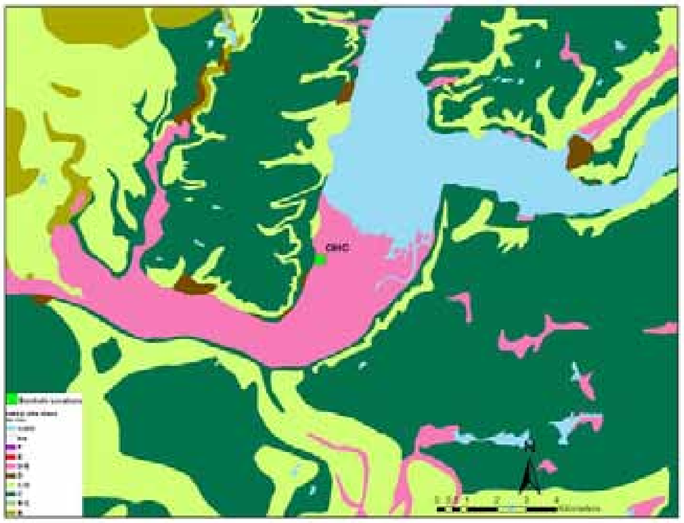

Figure 8: OHC site is underlain by NEHRP site class map (Palmer et al, 2004) for WA. The site was previously determined as NEHRP class D-E (stiff soil and soft soil).

Figure 9 shows shear-wave velocity profiles, combined with SPT-N blow counts, determined by processing the downhole shear-wave data. Both data sets were acquired from the 100-feet (~30 meters) deep borehole. Results from calculation of the NEHRP average shear-wave velocities for top 100 feet depth (Vs100) using fb, fp, fm and SPT-N data show that site class can be rated as D, although V100_fb gives site class C. Also, MASW results shown in Figure 10 give average Vs value which is in a good agreement with downhole seismic and SPT-N results. Table 3 summarizes all 100 feet (30 meter) NEHRP averaged values and site classes for OHC site.

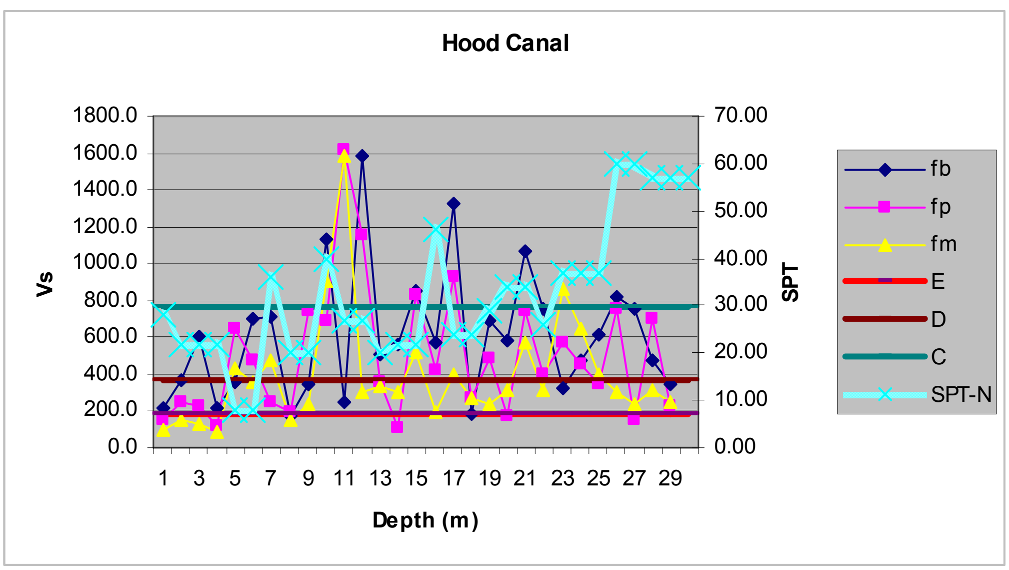

Figure 9: Velocity and SPT-N (blow counts) profiles for the OHC (Hood Canal) site. Symbols fb, fp and fm represents first break, first peak and first maximum, respectively, arrival times of the shear waves vibrating transversely to the source-receiver (radial) direction.

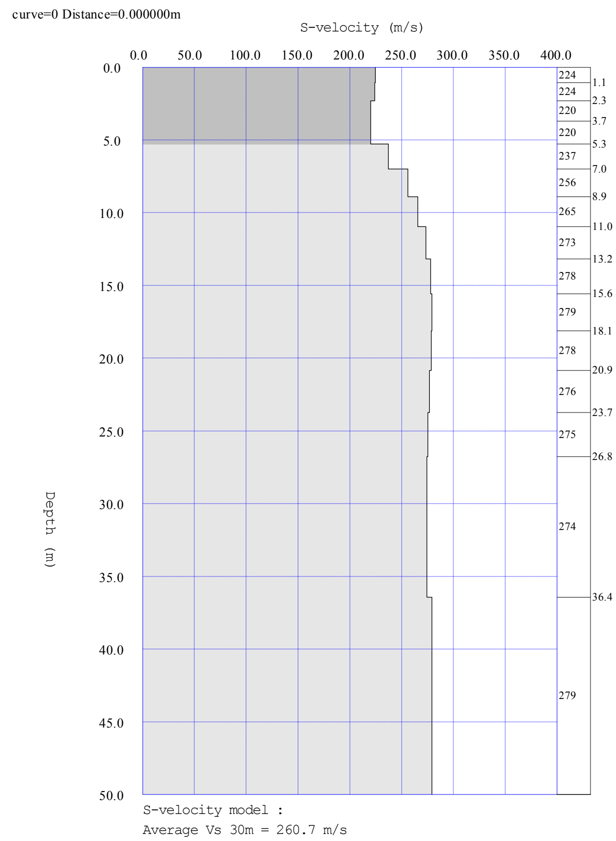

Figure 10: OHC: Shear-wave velocity profile determined using the MASW analysis. NEHRP average Vs100 = 853 ft/sec (~260 m/sec)

Table 3: OHC (Hood Canal) site calculated averaged Vs100 and SPT-N values and the corresponding NEHRP site classes (IBC 2006). Vs100 and N100 are averaged shear-wave velocities and SPT blow counts to top 100 ft (~30 meter) of soil column, respectively.

Values for OHS		NEHRP Site Class
Vs100_fb (ft/sec)	**1454**	**C**
Vs100_fp (ft/sec)	**1042**	**D**
Vs100_fm (ft/sec)	**866**	**D**
N100 (blow counts)	**28**	**D**
Vs100_MASW (ft/sec)	**853**	**D**
Interpreted NEHRP site class based on listed values above = D (since fb gives unreliable results)		

WISH (Wishkah) Site

Figure 11 shows site class map (Palmer et al., 2004) and the WISH strong motion site.

Figure 11: WISH site is underlain by NEHRP site class map (Palmer et al, 2004) for WA. The site was previously determined as NEHRP class C (very dense soil and soft rock).

Figure 12 shows shear-wave velocity profiles, combined with SPT-N blow counts, determined by processing the downhole shear-wave data. Both data sets were acquired from the 100-feet (~30 meters) deep borehole. Results from calculation of the NEHRP average shear-wave velocities for top 100 feet depth (Vs100) using fb, fp, fm and SPT-N data show that site class can be rated as C, although N100 gives site class C. Also, MASW results shown in Figure 13 give average Vs value which is in a good agreement with downhole seismic and SPT blow counts. Table 4 summarizes all 100 feet (30 meter) NEHRP averaged values and site classes for the WISH site.

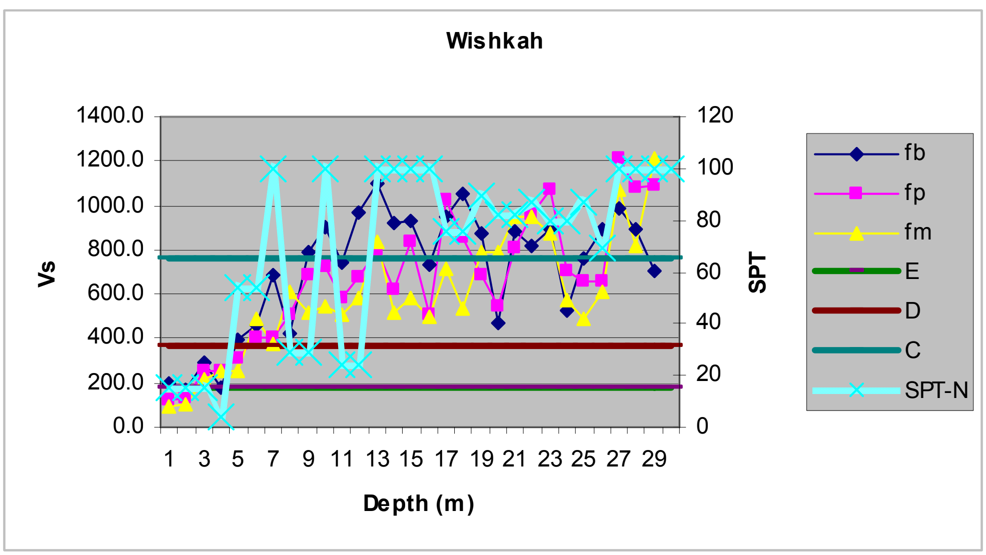

Figure 12: Velocity and SPT-N (blow counts) profiles for the WISH (Wishkah High School) site. Symbols fb, fp and fm represents first break, first peak and first maximum, respectively, arrival times of the shear waves vibrating transversely to the source-receiver (radial) direction.

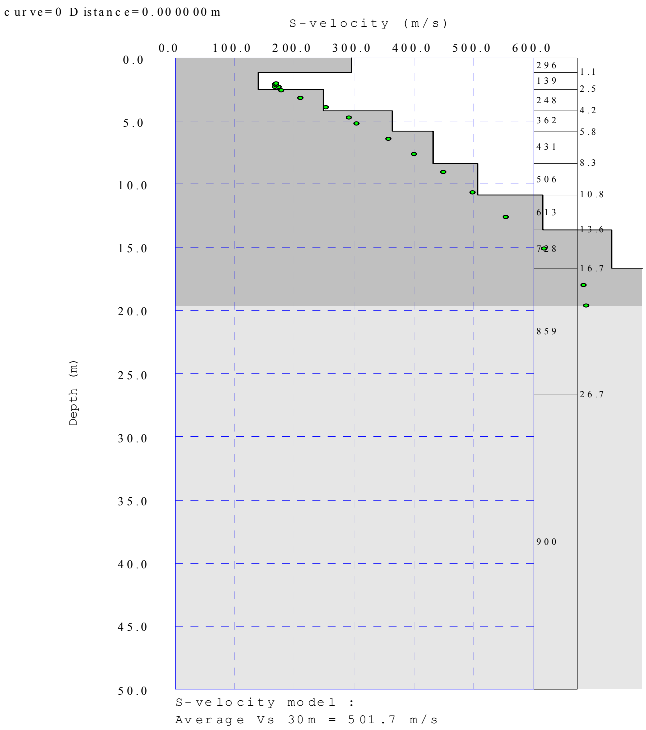

Figure 13: WISH: Shear-wave velocity profile determined using the MASW analysis. NEHRP average Vs100 = 1646 ft/sec (~502 m/sec).

Table 3: OHC (Hood Canal) site calculated averaged Vs100 and SPT-N values and the corresponding NEHRP site classes (IBC 2006). Vs100 and N100 are averaged shear-wave velocities and SPT blow counts to top 100 ft (~30 meter) of soil column, respectively.

Values for OHS		NEHRP Site Class
Vs100_fb (ft/sec)	**1793**	**C**
Vs100_fp (ft/sec)	**1600**	**C**
Vs100_fm (ft/sec)	**1384**	**C**
N100 (blow counts)	**34**	**D**
Vs100_MASW (ft/sec)	**1646**	**C**
Interpreted NEHRP site class based on listed values above = C		

Conclusions

The MASW compared to current and classical shear-wave source-receiver methods is very practical and productive method to determine NEHRP Vs30 values. Although some variations in Vs30 values are higher, overall site classes determined using invasive and noninvasive data are in a good agreement with 2004 site class map prepared by Palmer et al.(2004).

The MASW surveys for the four-borehole sites give reliable shear-wave velocity results that are consistent with downhole shear-wave velocities and SPT blow counts. Using the first peak and first maximum of transversely vibrating shear-wave (SH) arrival times give a more stable shear-wave velocity variation than using the first break arrival times. The first break time values (fb) are less stable than first peak and first maximum. Strong motion sites DNR (proposed), RHSS, OHC and WISH can be assigned to the NEHRP site classes D-E, C (or C-D), D (or C-D) and C (or C-D), respectively. Also, SPT blow counts are representative of soil conditions in the Puget Sound area.

This is ongoing project that requires more shear-wave data acquisition and compilation. Future work will be based on shear-wave database generation by conducting more MASW surveys and on dissemination of the pertinent database through DGER's interactive GIS mapping facility.

Acknowledgements

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References

Bodin, P., 2007, Written Communications.

IBC 2006, International Code Council, 2006, International Building Code: International Code Council, Inc., 666 p.

Miller, R.D., Xia, J., Park, C.B., and Ivanov, J., 1999, Multichannel analysis of Surface Waves to Map Bedrock, The Leading Edge, 18(12), 1392-1396.

Palmer, S.P., S.L. Magsino, E.L. Bilderback, J.L. Poelstra, D.S. Folger, and R.A. Niggemann, 2004, Liquefaction susceptibility and site class maps of Washington State. [URL: http://www.dnr.wa.gov/geology/pubs/ofr04-20/]

Park, C. B., Miller, R. D., and Xia, J., 1999, Multi-channel analysis of Surface Waves, Geophysics, 64(3), 800-808.

SeisImager/SW Manual, 2006, Windows Software for Analysis of Surface Waves, Geometrics Inc., 281pp.

Wong, I. and Stokoe, K., 2004, Geotechnical Characterization and Evaluation of Site Amplification at Selected PNSN Strong Motion Sites, Seattle, Washington. Progress Report, USGS Award Number 03HQGR0012.

Xia, J., Miller, R.D., and Park, C.B., 2000, Comparing Shear-wave Velocity Profiles form MASW with Borehole Measurements in Unconsolidated Sediments. Fraser River Delta, B.C., Canada: Journal of Environmental and Engineering Geophysics, 5(3), 1-13.

Electrical Resistivity Variations Before and After the Pingtung Earthquake in the Wushanting Mud Volcano Area in Southwestern Taiwan

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ABSTRACT

The extensive eruption of fluid from the mud volcanoes in the Yanchao area of southwestern Taiwan reveals the activities of the active Chishan fault. A series of time-lapse resistivity imaging measurements were initially conducted in the Wushanting Natural Landscape Preservation Area in Yanchao to evaluate the relationship between resistivity change and fault activity. Resistivity measurements were conducted first along seven 30- to 60-m survey lines to build up the regional model for mud volcanoes. We then conducted consecutive hourly and daily measurements to evaluate the short-term resistivity variations. Monthly observation was initiated along two 60-m lines in July of 2006. On December 26, 2006, two successive earthquakes with magnitudes of 6.96 and 6.99 hit the town of Hengchun in Pingtung County, about 120 km southwest of the monitoring site. Before the Pingtung earthquake, the resistivity at the research site was less than 25 ohm-m. Two regions with relatively low resistivity were found at a depth greater than 4-m at the positions of the two mud volcano craters. The two low-resistivity regions indicate the locations of conduits for the mud fluid. The major changes of resistivity are located in the vadose zone between the surface and a depth of 3-m. After the Pingtung earthquake, the maximum resistivity increased in the vadose zone by 7 ohm-m and 20 ohm-m on survey lines D and E, respectively. In the zone, the estimated water content of D and E decreased by 7% and 10%, respectively, after the earthquake. We suggest that the decrease of resistivity in the vadose zone most likely reflects the decrease of water content, itself caused by the earthquake tremors' increased emission of gas. Currently, we are continuing the resistivity-monitoring surveys and hope to provide more data to clarify the seasonal-variation patterns and to compare them with the previous findings.

Introduction

Mud volcanoes are geological features distributed in a wide variety of tectonic environments, such as passive continental margins, continental interiors, and transform and convergent plate boundaries (*e.g.,* Hedberg, 1980; Fertl and Timko, 1970; Higgins and Saunders, 1974; Reed *et al.,* 1990). In southwestern Taiwan, abundant mud volcanoes have erupted on land and offshore owing to the intense compression tectonic environment (Shih, 1967; Huang *et al.,* 1992; Liu *et al.,* 1997). Most mud volcanoes on land are related to geological structures and are distributed along the axis of the Gutingkeng anticline and the Chishan fault (Wang, 1988). The gas in mud volcanoes is believed to be closely related to decomposed organic matters in the mudstone formation. You *et al.* (2004) suggest that fluid emanating from Taiwanese mud volcanoes were originally marine pore waters that mixed with meteoric water, or that underwent surface evaporation during the recharge and discharge processes. Nevertheless, the gas-eruption activity of mud volcanoes are found to be closely related to tectonic activity (Sung *et al.,* 2004). It is difficult to estimate the gas volume correctly given the government restrictions on setting up any permanent instruments in the field, therefore it is necessary to look for other ways to monitor the gas-eruption activities quantitatively. In theory, the volume occupied by gas is more resistive than the water-saturated soil volume. If the eruption activity increases, the occupied gas volume should also increase. This premise makes it reasonable to measure the gas-eruption activity through electrical resistivity differences.

Electrical resistivity surveys employ a direct current or an alternating current of very low frequency and measure the variation of spatial potential fields to explore the distribution of the ground's apparent resistivity. Techniques for electrical resistivity monitoring have been successfully used for environmental purposes because of the techniques' abilities to identify resistivity changes stemming from either water-content variation in the vadose zone or the migration of contaminants (*e.g.,* Kean *et al.,* 1987; Van *et al.,* 1991). In this study, we attempt to quantify the mud volcano activity in the Wushanting Natural Landscape Preservation Area with surface electrical resistivity imaging profiling technology. The study was divided into three phases. In the first phase, we deployed seven survey lines, including four south-to-north 60-m long and three east-to-west 30-m long resistivity survey lines to investigate the background near-surface geology in the WNLPA. In the second phase, we collected hourly and daily time-lapse resistivity measurements along two survey lines to analyze the range of short-term variation. The design of the second phase is to study how the resistivity varies in a short period. The third phase included monthly measurements over a 10-month period to identify the long-term variation of the mud volcano activities, and to compare the resistivity variation with the tectonic activity.

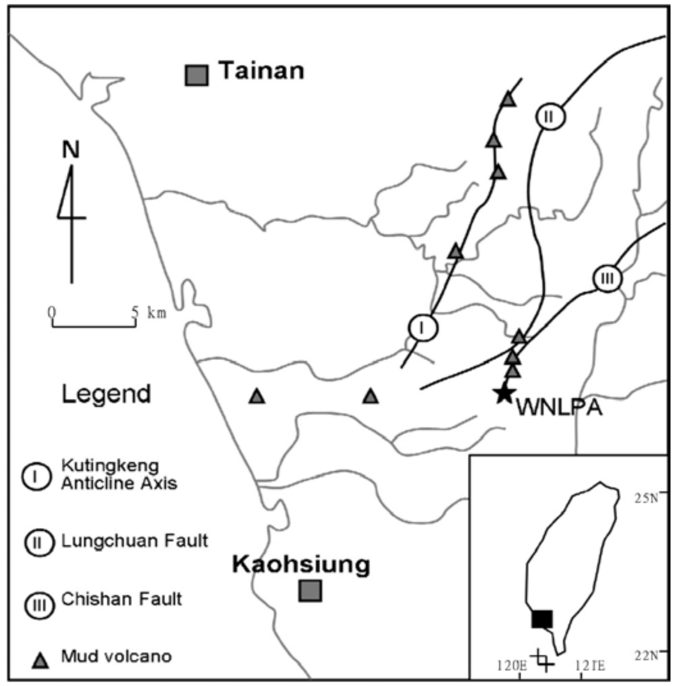

Figure 1. Regional maps showing the locations of mud-volcano groups (LC, TKS, AKS, KSP, LYS, and WST) in southwestern Taiwan. The star sign shows the location of the Wushanting Natural Landscape Preservation Area (WNLPA) site. The Cross labels in the lower right small map indicate the two epicenters of the Pingtung doublet earthquake.

Site Description

Taiwan is located at the boundary of the Philippine Sea plate and the Eurasia plate. At least 17 major mud volcano sites can be identified in southwestern Taiwan. Among them, the Wushanting Natural Landscape Preservation Area (WNLPA) (Fig. 1) is located near the Chishan fault in Yanchao, Taiwan. The eruption of fluids and gases from the fissures in the thick Gutingkeng mudstone resulted in two huge cone-shape landscape features. The Gutingkeng formation is mainly Pleistocene marine gray mudstone intercalated with thin-bedded sandstone (Keng, 1981), and clay particles can constitute about 59% of the formation's content. The thickness of the formation reaches is over 5,000 m.

The mud volcanoes in the WNLPA are located in a 200-m × 150-m platform (Fig. 2(a)). There were originally three main mud volcano craters in the platform. A new eruption crater was formed beside the B crater after the Pingtung earthquake in December 2006. Constantly erupted mud fluids almost entirely eliminate plants from the ground near the craters. The unique geomorphic features have led the government to designate the WNLPA site a natural landscape preservation area in the county.

We chose the surface electrical resistivity imaging profiling (RIP) method for this study because government policies prohibit establishment of permanent instrumentation in the WNLPA. The LGM 4-point Light hp resistivity meter and ActEle system (Lippmann, 2005) were used for the field resistivity measurements. For the resistivity measurements in the first phase, we selected dipole-dipole and Wenner arrays because they provide lateral and vertical coverage of the subsurface. To construct the geology model of the WNLPA site, we performed data acquisition with 40 electrodes spaced at 1.5-m intervals along the south-to-north lines (lines C, D, E, and F in Fig. 2(b)), and with 20 electrodes along the east-to-west lines (lines X, Y, and Z in Fig. 2(b)). To address the lateral resistivity variation and to use our survey time efficiently, we used only the dipole-dipole method during the second and the third phases of the research. In the second phase, we conducted measurements along the D and E lines with the same 1.5-m electrode spacing to monitor short-term variations in resistivity. The short-term monitoring was conducted in two different time frames: first we carried out monitoring every hour for 8 consecutive hours, and then we resumed the monitoring, carrying it out once a

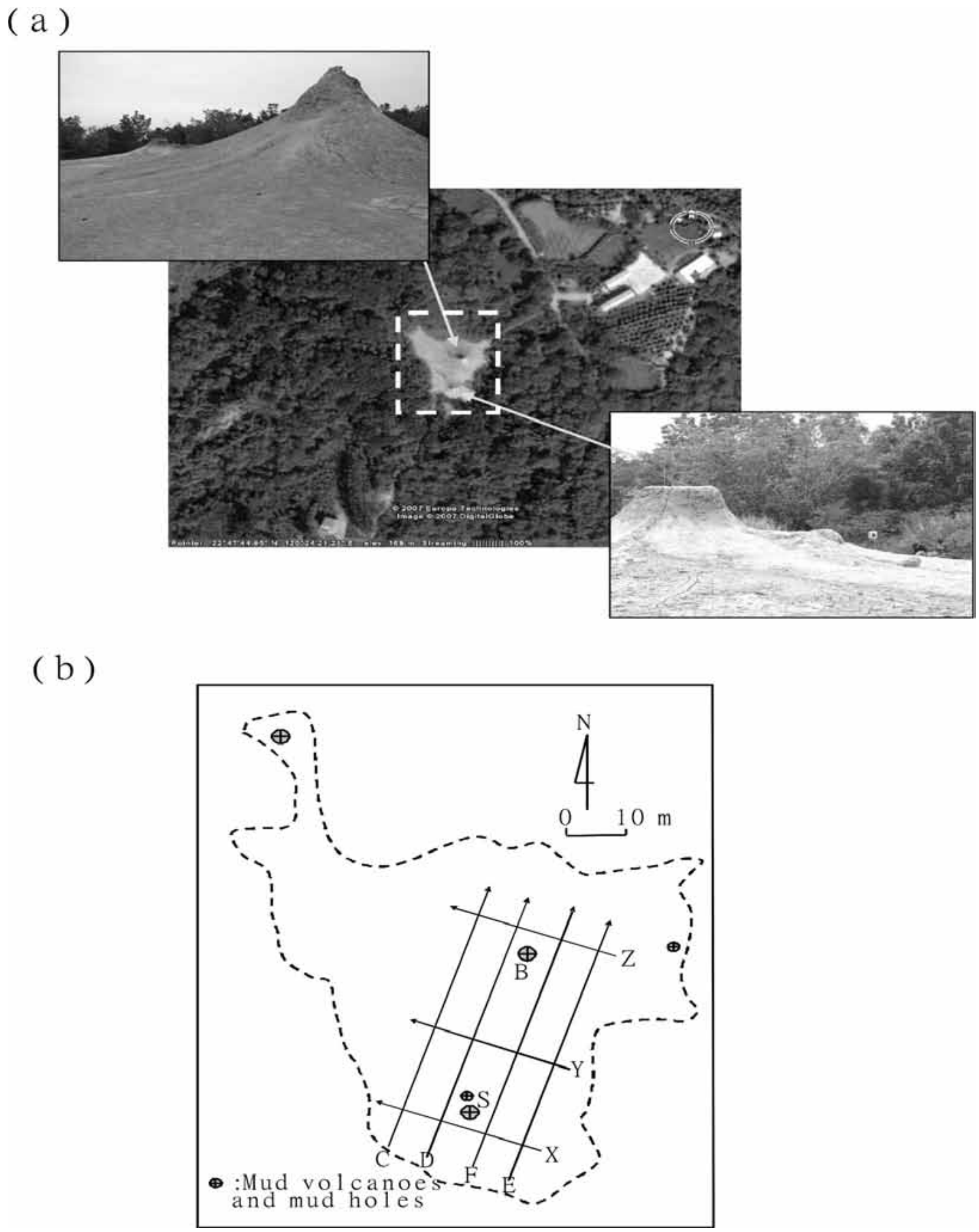

Figure 2. (a) Satellite image of the WNLPA (from Google™ earth) and pictures of the mud volcano B (upper left) and mud volcano S (lower right). (b) Resistivity survey plan of the WNLPA site (dotted line indicates the range of the WNLPA). B and S mark the locations of two major mud-volcano craters. Resistivity surveys were conducted along the C, D, E, and F lines and along the X, Y, and Z lines. Arrows show the survey direction.

day for one week. In the third phase, we collected resistivity data along the D and E lines with the same 1.5-m electrode spacing for 10 mo. Because precipitation may affect the resistivity measurements, we took no resistivity measurements during the three days following significant rainfall; in this way, we sought to avoid a situation where the precipitation would affect our long-term monitoring study. As a result, the frequency of the long-term measurement was roughly once a month, with the frequency varying in relation to weather conditions. Resistivity data were inverted with EarthImager™ 2D software (AGI, 2006), which uses a forward modeling subroutine and non-linear optimization techniques to calculate resistivity values.

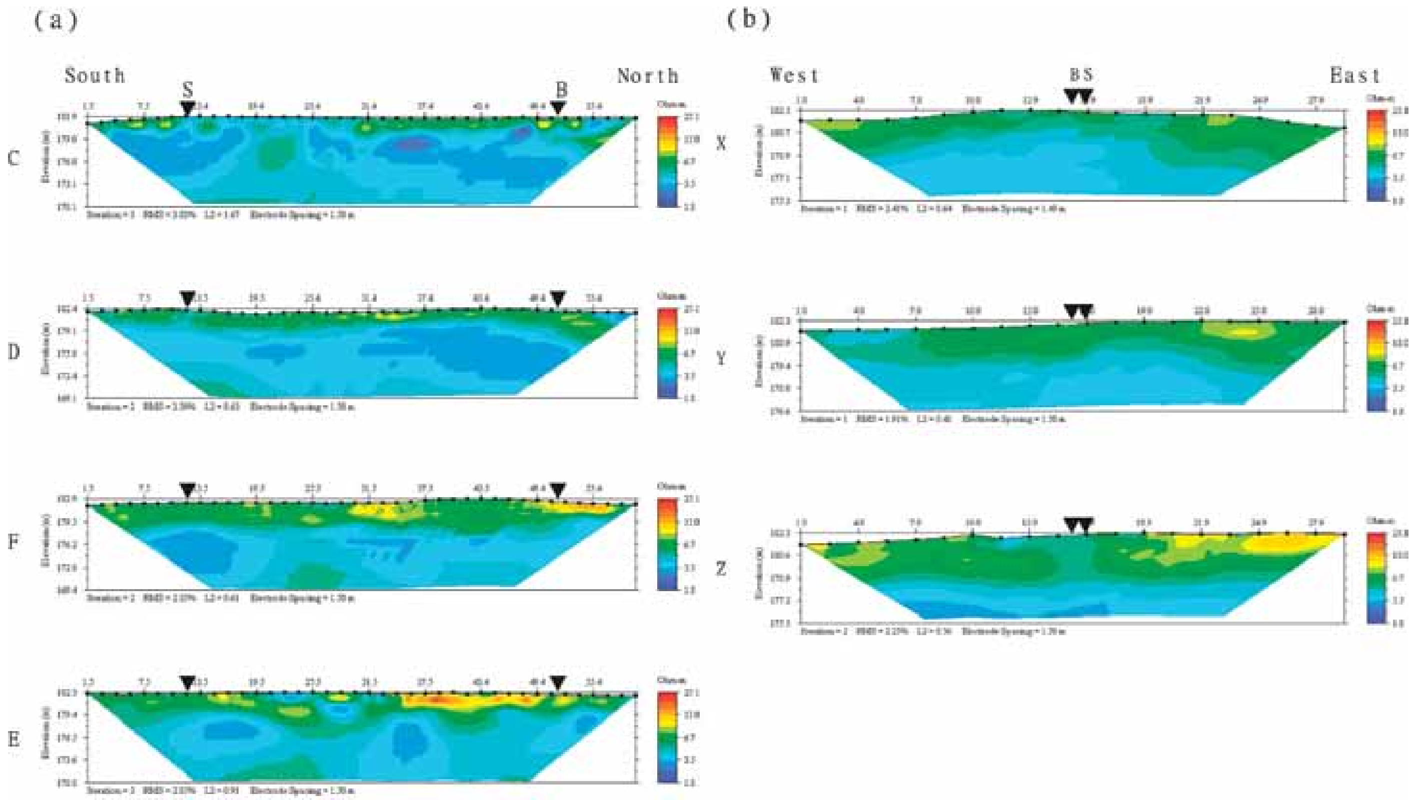

Figure 3. (a) Inverted resistivity imaging profiles of the north-south C, D, E, and F lines collected at the WNLPA site in July 2006. B and S indicate the projected locations of the two mud-volcano craters. (b) Inverted resistivity images of the east-west X, Y, and Z profiles.

Results

Background Resistivity

The dipole-dipole and Wenner-resistivity surveys were conducted on July 22, 2006 (during the first phase), to construct the background model of the WNLPA site. The acquired dipole-dipole and Wenner data were then combined and inverted together using the AGI EarthImager^{TM} 2D software (AGI, 2006). Figure 4 shows the inverted resistivity of the north-south C, D, E, and F lines and the east-west X, Y, and Z lines. Symbols B and S indicate the projected positions of the mud volcano craters. The horizontal distance, shown in images in Fig. 3, indicates the displacement from the position of the reference electrode in each survey line. Because lines C, D, E, and F (Fig. 3(a)) had longer survey distances, and therefore allowed for larger electrode spacing, the resistivity-exploration depth for lines C, D, E, and F is larger than that for lines X, Y, and Z (Fig. 3(b)). In general, the inverted resistivity ranged from 2 to 16 ohm-m for the mudstone in the WNLPA site. The vadose zone, which is located at the surface and is more resistive than the underlying saturated layer, is about 2–3 m thick in the study area. Regarding high resistivity regions (regions wiyh resistivity greater than 10 ohm-m), lines E and F exhibited resistivity values greater than the resistivity in the C and D lines. Line Z exhibited resistivity that was greater than the resistivity in lines X and Y. Because of the geology in the WNLPA site, these regions may constitute a "drier zone" than the rest of the vadose zone. We located low resistivity regions (regions with resistivity less than 4 ohm-m) under the two mud volcano craters in lines D, E, and F. Because the mud volcanoes are still emitting gas and mud fluids from craters, the low resistivity region may indicate the presence of fissures where the mud fluids existed.

Results from surveys along lines C, D, E, and F were combined together, and the data between lines were then interpolated with the simple kriging method; in this way, we formed the resistivity layered model of the WNLPA site shown in Fig. 4. In Fig. 4, a high resistivity region (with resistivity over 10 ohm-m) appears in the southeast part of the WNLPA within 4-m of the surface. Compared to the rest of the area, the drier region is located in the high ground formed by the mud emitted from the mud volcanoes. This region's characteristics imply that the southeast WNLPA site has a thicker vadose zone with less water content above the shallow water table. Regarding the mudstone deeper than 4-m, we identified two isolated low-resistivity

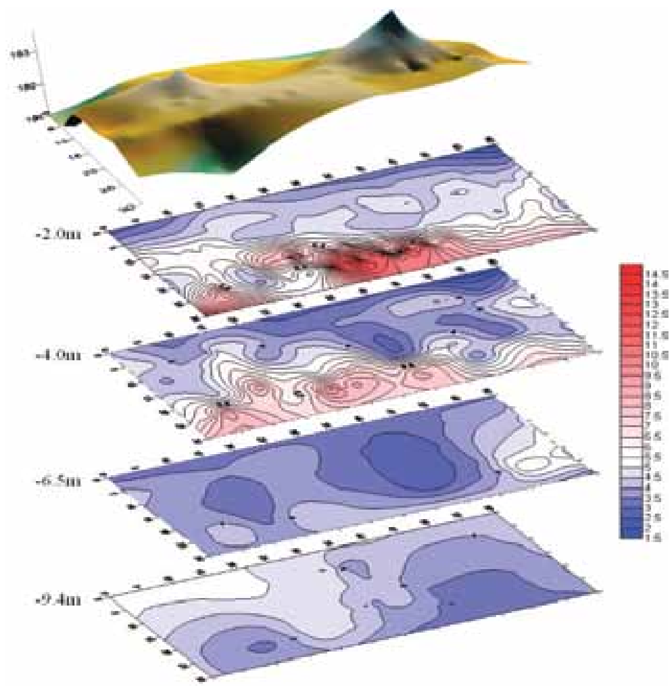

Figure 4. Background resistivity images collected at the WNLPA site in July 2006. The resistivity image of each different depth was created by applying the kriging method to the inversion results from the C, D, E, and F lines and from the X, Y, and Z profiles.

regions (with resistivity less than 4 ohm-m) under the two mud volcano craters. The location-related consistency between the very low resistivity region in the deeper subsurface and the mud volcano craters on the ground surface suggests fissure conduits of oversaturated mud are present.

Short-term Variation of the Resistivity

The short-term (daily) resistivity variations were monitored prior to monitoring the long-term (monthly) resistivity changes. Evaluation of the short-term variations allowed us to distinguish the accumulated long-term deviations from the hourly or daily variations. Dipole-dipole surveys were first conducted along line D every hour for 7 consecutive hours to assess the variation from hour to hour. Figs. 5(a)–(b) show the average resistivity and the standard deviation of the hourly surveys, respectively. Figure 6(a) shows that the resistive layer exhibiting resistivity over 5 ohm-m has a depth less than 3 m. Furthermore, regions with higher resistivity (>9 ohm-m) are located at the positions near the two mud volcano craters. Also, as Fig. 5(b) shows, most of the line D's standard deviation values in the 7-hour period are less than 1 ohm-m. The maximum standard deviation is about 4.0 ohm-m and is found only at two surface points, located at 13-m and 44-m from the reference electrode. The hourly observation shows no significant resistivity variation during the study period. This

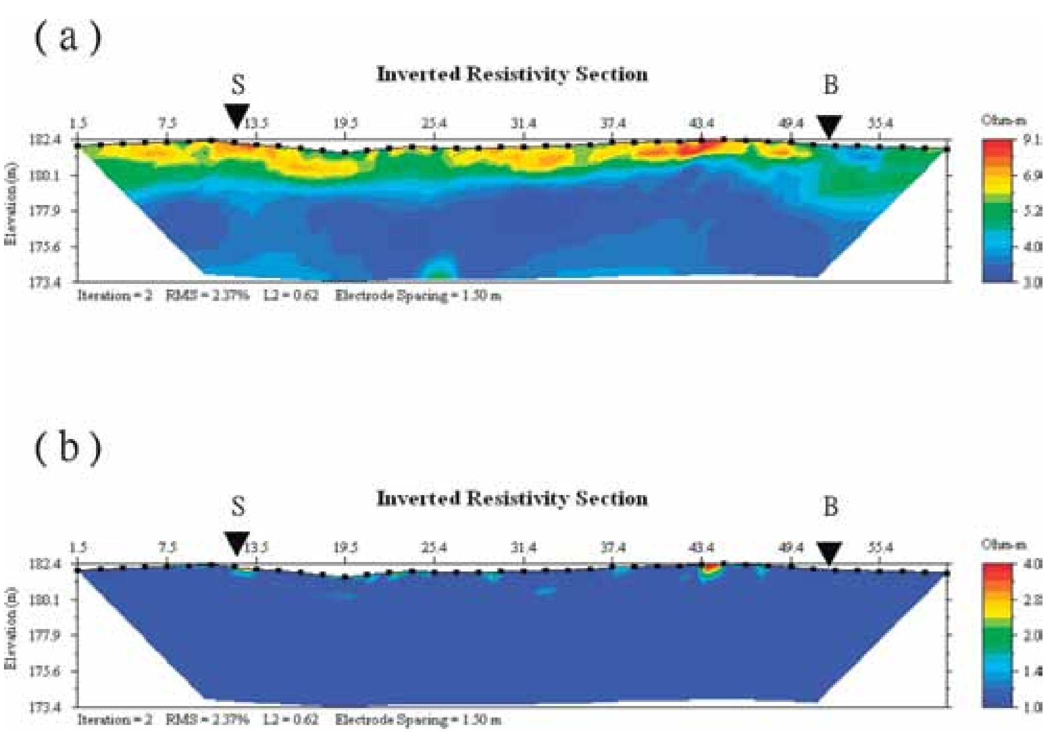

Figure 5. (a) Average resistivity of the hourly surveys along the D line. (b) Standard deviation of resistivity of the hourly surveys along the D line.

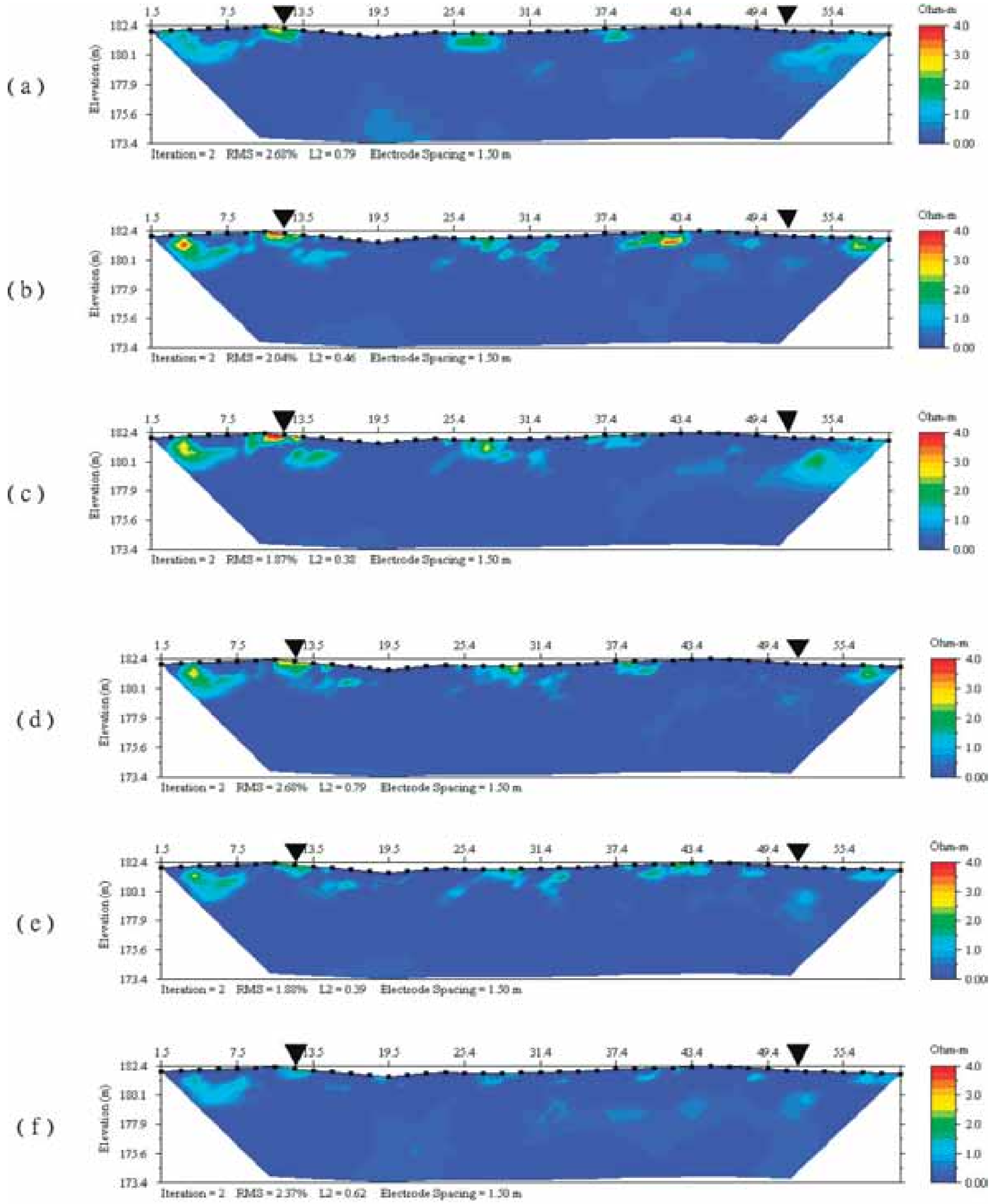

Figure 6. Resistivity difference in the background data collected at (a) day 2, (b) day 3, (c) day 4, (d) day 5, (e) day 6, and (f) day 7 in the 7-day observation study.

finding implies that the influences from the hourly change of climate conditions are minor during the observation period along the D profile.

After the completion of hourly observations on day 1, we commenced the daily observation for six consecutive days. During the entire 7-day period, there was no precipitation in the study area. Figures 6(a) to 6(f) illustrate the resistivity difference with respect to the background at day 1. Figure 6(a) illustrates the finding that, at day 2, regions exhibiting sporadic resistivity-related changes over 1 ohm-m appeared near the surface locations. The precise ranges of these locations are as follow: from 1.5-m to 4-m, from 10-m to 13.4-m, from 25.4-m to 27.4-m, from 37-m to 38-m, and from 55.4-m to 59.5-m. Most of the regions were not deeper than 3-m from the surface (Fig. 6). At day 3, the region between 37-m and 38-m broke down into several smaller regions, and the rest of the regions' maximum changes in resistivity increased to over 2.5 ohm-m (Fig. 6(b)). Regarding the region that was from 10-m to 13.4-m, the maximum change in resistivity increased to over 4 ohm-m at day 4 (Fig. 6(c)) and then decreased to about 3.0 ohm-m by day 5 (Fig. 6(d)). Figures 6(e) and 6(f) illustrate the same trend of decreasing resistivity as that at day 5 for all anomalous regions at day 6 and day 7.

Our examination of daily variations has helped us to evaluate the range of daily variation and the trend of daily resistivity change. In summary, the results of our daily resistivity observations indicate that most of the anomalous resistivity regions during the 7-day period were located no deeper than 3-m from the surface. The daily resistivity change varied systematically between 2 ohm-m and 5 ohm-m at the WNLPA site. The absence of drastic daily resistivity variation over 5 ohm-m implies that the resistivity variation at the WNLPA site is progressive and that the long-term resistivity change over this range can be viewed as the consequences of accumulated short-term changes, rather than as short-term peaks.

Monthly Variations in Resistivity

It was expected that the resistivity change of mud volcanoes would take place around the vertical fault fissures, as mentioned in the previous section. Therefore, we used RIP measurements with the dipole-dipole electrode configuration along the D and the E survey lines. The observation period extended from July 2006 to April 2007. During the long-term observation, two successive earthquakes with magnitudes of 6.96 and 6.99 hit southern Taiwan offshore of the Hengchun twon, Pingtung County, on December 26, 2006 (Chen *et al.*, 2008). The epicenters of the Pingtung doublet earthquake were about 120 km southwest of the WNLPA site (locations of epicenters of the Pingtung doublet earthquake are indicated in Fig. 1). In the WNLPA area, earthquake magnitude measured is about 5 (CWB, 2006) for the Pingtung earthquake. This major earthquake constituted an extraordinarily useful event for our long-term resistivity study. Therefore, we took two additional measurements immediately after the earthquake to evaluate whether or not the earthquake significantly affected the activity of the mud volcanoes.

Based on background that we collected on July 22, 2006, Fig. 7 illustrates (1) the inverted long-term resistivity of the D profile and (2) the difference between the observed resistivity and the background. The resistivity images of the D profile show that a relatively resistive zone (resistivity higher than 5 ohm-m) existed at the shallow subsurface above 181 m (about 0-m to 3-m in depth). We had identified this resistive region as the near-surface vadose zone in the study's first phase. Before the Pingtung earthquake (Dec. 26 2006), the major resistivity increase was in the vadose zone. Several regions with resistivity anomalies less than 5 ohm-m appeared sporadically in the vadose zone. In general, the resistivity change before the earthquake was less than the range of the short-term variation. Two days after the Pingtung earthquake, the maximum resistivity increase reached about 10 ohm-m, twice the short-term variation range in the D profile. A similar increased resistivity in the shallow subsurface was reported by Yang *et al.* (2002) after the Chi-Chi earthquake in the hanging wall of the Chelungpu fault zone. By April 14, 2007, the measured resistivity anomaly increased to over 12 ohm-m near the S mud volcano crater. Unfortunately, we did not have the day-to-day measurements to verify whether these data reflected the real resistivity change near the S mud volcano crater or were simply data offset owing to an unidentified equipment-setup problem.

Figure 8 shows the resistivity images and the resistivity difference to the background of the E profile. The images show that several anomalous resistivity regions were developing above 3-m in depth in the vadose zone throughout the monitoring period. The maximum resistivity anomaly gradually increased and reached about 12 ohm-m by December 17, 2006. On December 28, two days after the Pingtung earthquake, the E profile's maximum resistivity increased to over 20 ohm-m near the surface. The earthquake-induced increase in the E profile's maximum resistivity was about three times larger than that of the nearby D profile's maximum resistivity. The maximum resistivity increases were over 20 ohm-m on January 14 and February 28 in 2007, but only slightly greater than 15 ohm-m on April 14, 2007. In conclusion, the E profile's resistivity in the vadose zone increased to over 20 ohm-m owing to the Pingtung earthquake, and slightly decreased four months after the earthquake.

Discussion

There are many possible reasons for the changes in resistivity; such as temperature, precipitation, earthquake activity, and their subsequent influence (namely, gas or fluid emissions from the subsurface). Since we did not take measurements within three days following precipitation events, we should be able to rule out precipitation influence. Besides the precipitation, the temperature may affect the resistivity variations. After examining the daily temperature records during the monitoring period (Fig. 9), we concluded that the resistivity roughly decreases by about 0.7 ohm-m when

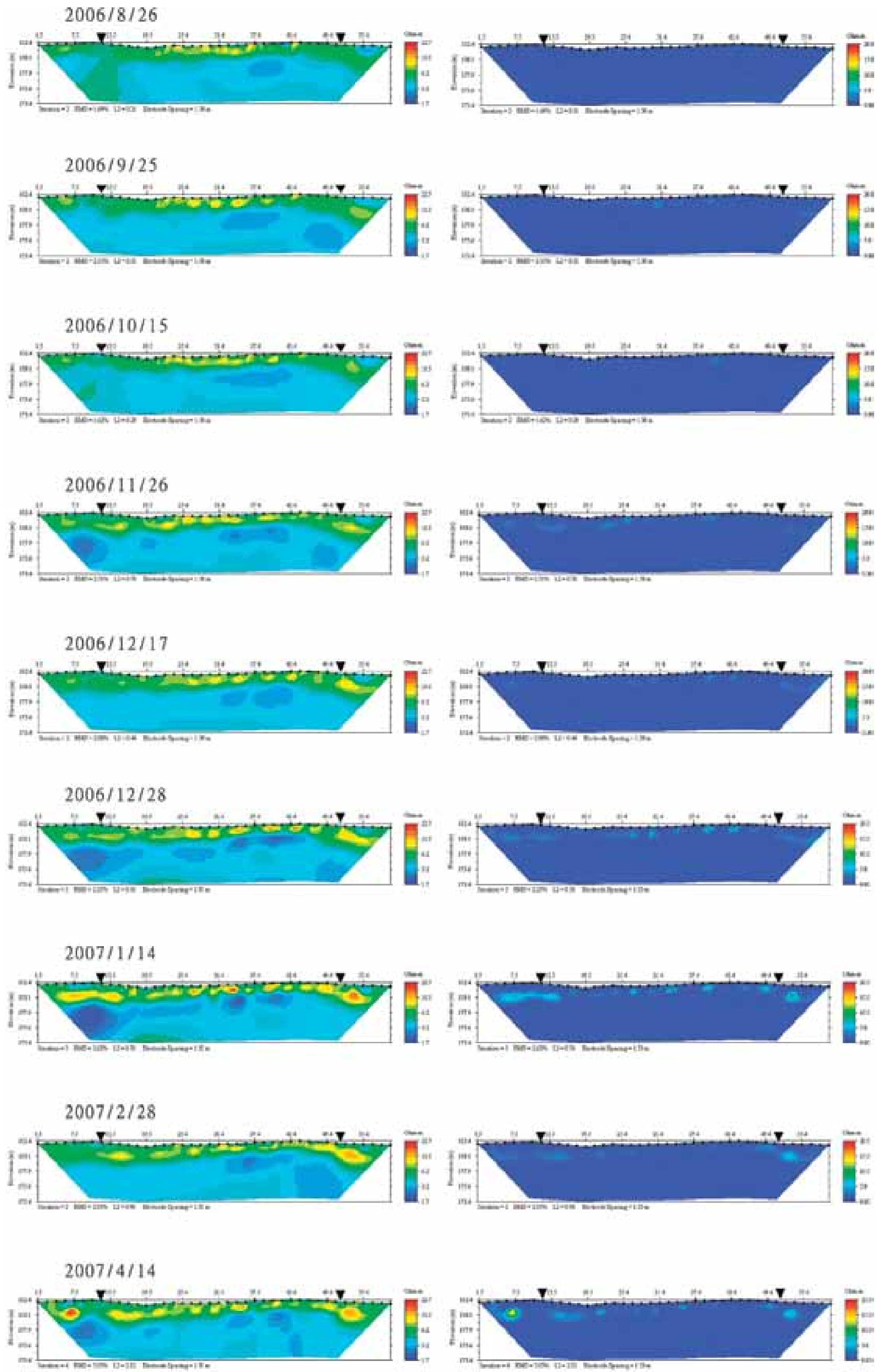

Figure 7. Left: the inverted resistivity images of the D line with respect to the long-term monthly observation. Right: the resistivity difference of the D line to the background data (July 22, 2006).

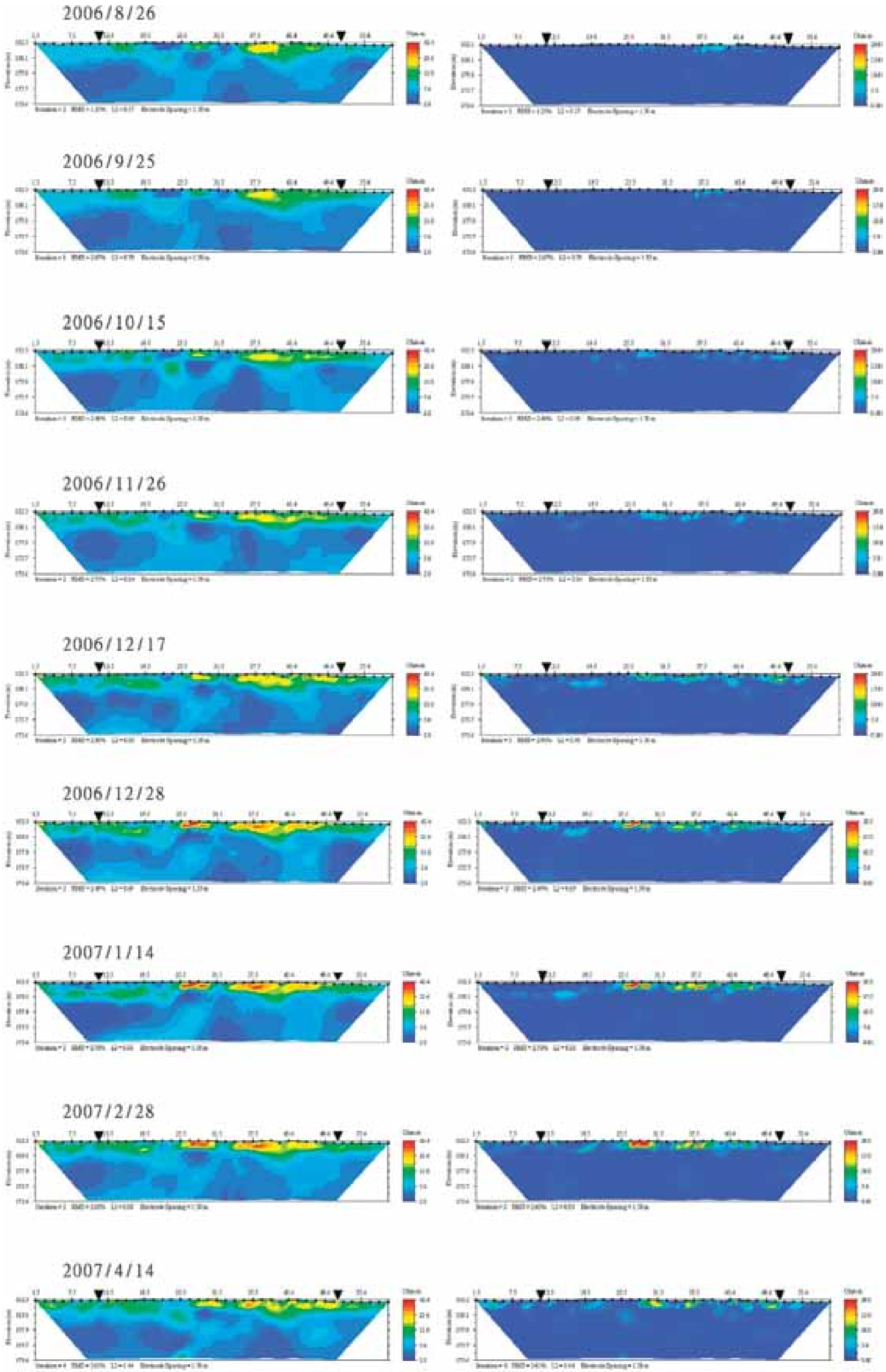

Figure 8. Left: the inverted resistivity images of the E line for long-term monthly observations. Right: the resistivity difference of the E line with respect to the background data (July 22, 2006).

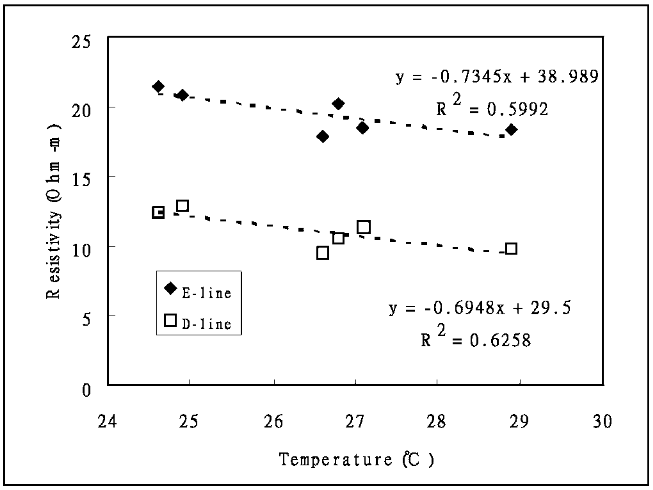

Figure 9. Comparison of maximum resistivity of D and E lines and the ground temperature before the Pingtung earthquake. Dashed lines are the regression lines of the D and E profiles.

the daily average temperature increases by 1°C. The temperature was not likely the major factor causing the abrupt resistivity decrease after the Pingtung earthquake since the average temperature only decreased 5–7°C in December at the WNLPA site. Therefore, we suggest that the decrease of resistivity in the vadose zone of the D profile and the E profile most likely stemmed from the earthquake activities.

In addition, there is a radon activity monitoring site located about 500 m south of the WNLPA in the Campus of National Kaohsiung Normal University. Figure 10(a) shows the variations of radon activities during 2006 and 2007. Unfortunately, the instrument appears to encounter some problems in recording the radon data in July and August of 2006 and also in February of 2007. We found that the radon activity recorded by the instrument seems to have gradually recovered to a steady state after October 2006. In Fig. 10(b), we show the half-week maximum radon activity from October 2006 to January 2007. The peak values of the radon activity variations seem to be correlated well with the highest and lowest temperatures of every month, except for the peak appearing at the time of the Pingtung earthquake. Although the radon activities are affected primarily by the temperature, the extraordinary peak at the Pingtung earthquake suggests excess gas emission in the area. We further compared the resistivity at 1.2-m deep to the methane gas flux collected by Hong *et al.* (2009) at the surface in WNLPA. Methane

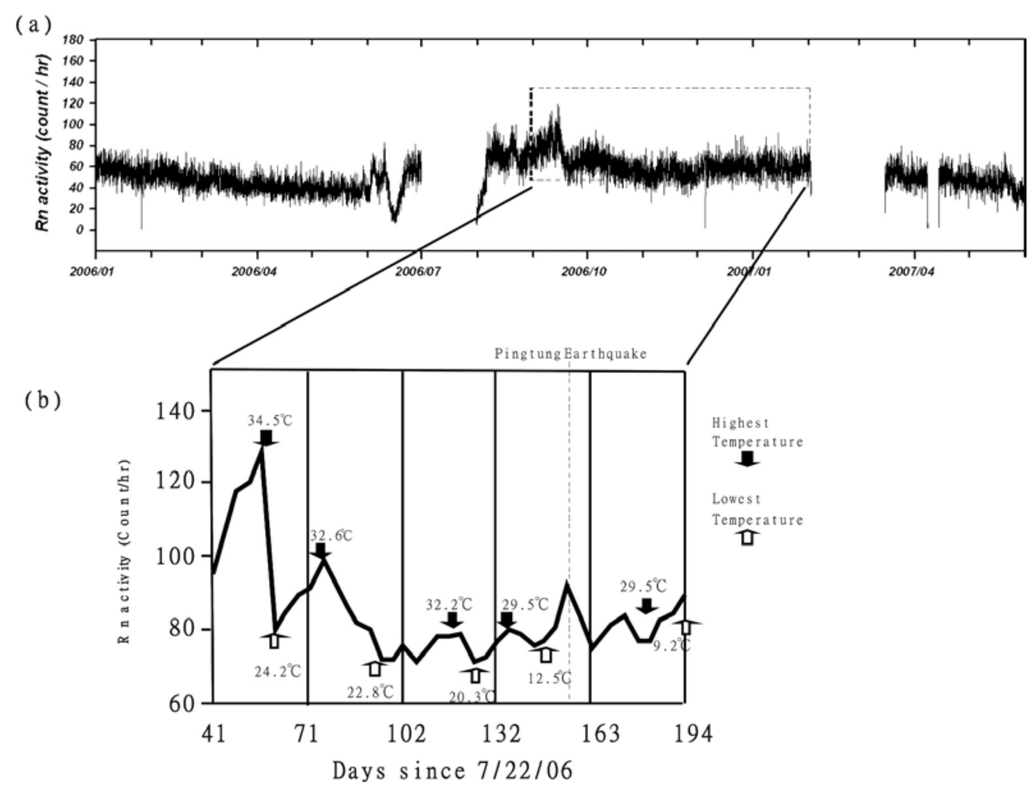

Figure 10. (a) Radon activity records during 2006 and 2007. (b) Variation of half-week maximum radon activities from October 2006 to January 2007. Black arrows show the highest temperatures of the month, and white arrows show the lowest temperature of the month. (The time scale is converted into days since 7/22/06 to be compared with the resistivity variations).

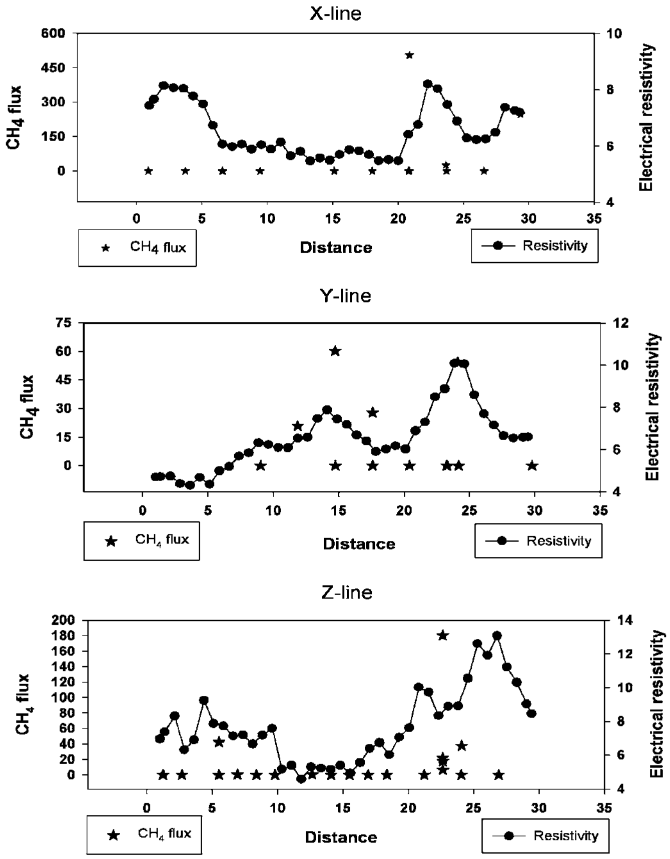

Figure 11. Spatial distribution of 2-D electrical resistivity at a depth of 1.2 m and micro-seepage of CH4 flux measured by Hong *et al.* (2009) in the WNLPA. Methane flux measurements close to X, Y, and Z lines were projected on those profiles for comparison.

measurements near the resistivity survey lines were selected and projected onto the resistivity profiles. In Fig. 11, the high resistivity regions can be correlated to the areas with high methane flux. Therefore, we concluded that the earthquake likely induced a greater-than-usual emission of gas from the gas-saturated mud fluid in fault fissures. The emitted mud fluid would have formed a thin impermeable cap and the gas would then have accumulated near the surface, resulting in the decreased water content and the higher resistivity in the vadose zone.

To estimate the change of water content in the vadose zone at the WNLPA site, we took several soil samples along the perimeter of the WNLPA site (because no sampling is allowed inside the protection zone). We conducted the "beaker test" in the laboratory to create circumstances that would enable us to identify the relationships between the water content and the resistivity at the WNLPA site. Soil samples were heated for 24 h in a 105°C oven and then packed, in equal parts, into several 1-liter beakers and weighed. The thickness of the soil samples was maintained at least 6-cm from the bottom of the beakers to ensure the absence of boundary interruptions. We added various volumes of water into the beakers and sealed the top of the beakers for a day. Next, the beakers were weighed and the resistivity was measured using a Wenner array with electrodes spaced 2-cm apart. Lastly, the soil samples were weighted again to allow correction for evaporation (loss of water) during the measurements. The beaker test provides a quick way to build the resistivity-"water content" relationships in the laboratory. In addition, the test enabled us to easily measure the oversaturated condition.

Though the WNLPA site is located in the mudstone area, the grain-size analysis shows that soil samples contained 4.0% clay, 67.1% silt, and 28.9% sand. Researchers have proposed various empirical and theoretical equations to describe the relationships between water content and measured bulk resistivity for soils and rocks, an example being Archie's empirical equation (Archie, 1942). In this study, we adopted a single power-law function similar to that of LaBrecque *et al.* (2002). The relationship between bulk resistivity and water content can then be described as

$$\rho = a \cdot \theta^{-b}, \tag{1}$$

where ρ is the bulk resistivity, θ is the volumetric water content, and a and b are the empirical constants that were determined through a comparison of measured resistivity to water content in the beaker test. Noting that parameters a and b might vary between the lab-scale test and the field experiment, we used only the empirical relationships built in the beaker test to conduct a rough evaluation of the water content's variation range at the WNLPA site. Here, we determined $a = 3.5$ and $b = 0.81$ from the unsaturated results of the beaker test shown in Fig. 12. Figure 13 shows the variations of the maximum resistivity and the estimated water content on the D and E profiles during the observation periods. After the Pingtung earthquake, the maximum resistivity increased by 10 ohm-m and 25 ohm-m on the D and E profiles (Fig. 13(a)), respectively. The estimated post-earthquake water content, however, decreased by 7% and 10% for the D and E profiles, respectively, in the vadose zone (Fig. 13(b)). The similar water-content change of the D and E profiles further indicates that the released excess gas caused by the earthquake may be the reason for the WNLPA site's change in resistivity.

Conclusions

To examine the influence of fault activities on the subsurface resistivity, we conducted a three-phase study

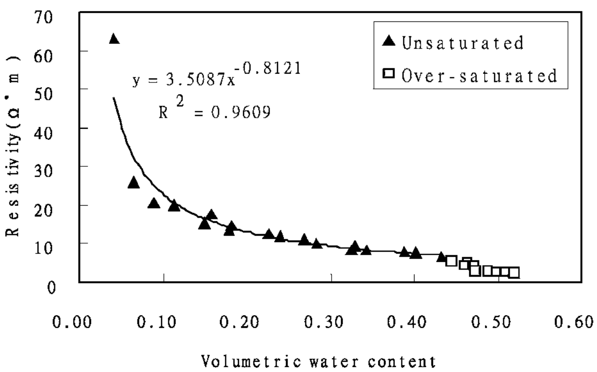

Figure 12. The relationships between the water content and the measured resistivity for the mud samples collected at the area adjacent to the WNLPA site.

at the Wushanting Natural Landscape Preservation Area site. In the first phase, we attempted to establish a geological model by conducting resistivity imaging surveys. Two isolated conductive regions were identified at a depth greater than 4-m below the surface. The positions of the conductive regions are correlated to the two mud volcano craters at the surface. The correlation suggests the locations of mud-fluid conduits in the mudstone fissures. In addition, the location of the unsaturated vadose zone is less than 4-m from the surface at the WNLPA site, and the thickness of the vadose zone decreases from the southeast corner to the northwestern part of the WNLPA.

To examine the range of short-term resistivity variation, we conducted hourly and daily measurements along a fixed survey line in the second phase of the study. The results of the hourly observations show that most of the resistivity standard deviations were less than 1 ohm-m in the 7-hour period. The hourly observations show no resistivity variation over 5 ohm-m during the study period. This finding implies that the influences from the hourly change of climate conditions were minor during the observation period. In addition to the hourly observation, the daily resistivity change varied systematically within a range of 5 ohm-m at the WNLPA site. Therefore, it appears that we can identify the long-term changes in resistivity on the basis of the short-term variations if the resistivity difference relative to the daily background is greater than 5 ohm-m.

In the third phase, we tried to evaluate whether or not the long-term resistivity variations were correlated to the local tectonic activities. During the period, the major changes of resistivity were located between the surface and a depth of 3 m. On December 26, 2006, doublet earthquakes occurred offshore near the town of Hengchun in Pingtung, about 120 km southwest from

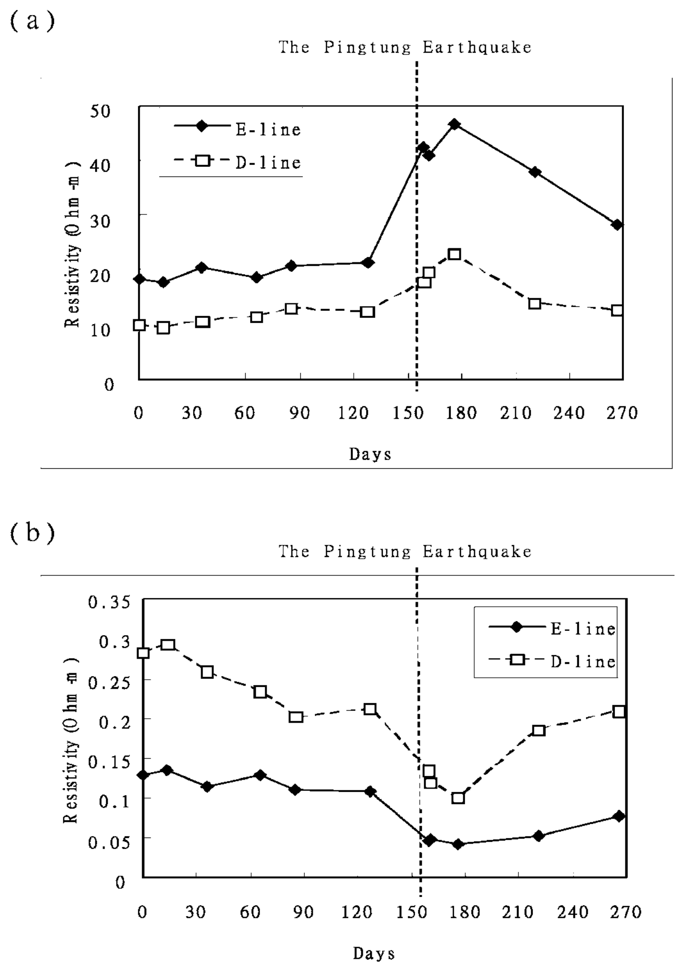

Figure 13. (a) Variation of the maximum resistivity of both the D line and the E line during the observation period. (b) Variation of the estimated water content of both the D line and the E line during the observation period.

the monitoring site. The Pingtung earthquake provided us a perfect opportunity to evaluate any change in the study area's resistivity. After the Pingtung earthquake, the maximum resistivity anomaly increased to 7 ohm-m and 20 ohm-m on two survey lines (D and E, respectively). The estimated water content decreased by 7% and 10% in the vadose zone on the D and E profiles after the earthquake. The similar water content change suggests that the released excess gas caused by the earthquake may be the reason for the decreased water content and, thus, for the increased resistivity in the vadose zone at the WNLPA site. From the results of our study, we observed that the tectonic activities may have significant influences on the vadose zone at the WNLPA site. It is reasonable to expect that the pressure wave may induce the release of a gas-saturated liquid from the saturated zone and, thus, cause the decreased water content in the vadose zone. This finding suggests that well-controlled resistivity imaging in the vadose zone may provide researchers a useful and economical tool with which they can evaluate the potential and the actual effects of tectonic activities. Currently, we are continuing our resistivity monitoring surveys and hope to provide more data for evaluating the relationships between released gas volume and tectonic activities.

Acknowledgements

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References

AGI, 2006, Instruction Manual for EarthImager 2D ver. 2.3.0: Advanced Geosciences, Inc., Austin, Texas, 139 pp.

Archie, G.E., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics: American Institute of Mining and Metallurgy, **146**, 54–62.

Chen, H.Y., Lee, J.C., Kuo, L.C., Yu, S.B., and Liu, C.C., 2008, Coseismic surface GPS displacement and ground shaking associated with the 2006 Pingtung earthquake doublet, offshore southern Taiwan: Terr. Atmos. Ocean. Sci., **19**(6) 683–696.

Chow, J.J., Chang, S.K., and Yu, H.S., 2006, GPR reflection characteristics and depositional models of mud volcanic sediments—Wushanting mud volcano field, southwestern Taiwan: Journal of Applied Geophysics, **60**, 179–200.

CWB, 2006, Earthquake Report 107: The Central Weather Bureau, Taipei, Taiwan. http://www.cwb.gov.tw/V5e/index.htm.

Fertl, W.H., and Tinmo, D.J., 1970, Occurrence and significance of abnormal-pressure formations: Oil and Gas Journal, **5**, 97–108.

Garambois, S., Sénéchal, P., and Perroud, H., 2002, On the use of combined geophysical methods to assess water content and water conductivity of near-surface formations: Journal of Hydrology, **259**, 32–48.

Hedberg, H.D., 1980, Methane generation and petroleum migration *in* Problems of petroleum migration: Geologist studies in geology 10, Roberts, W.H., and Cordell, R.J. (eds.), The American Association of Petroleum Geologist, Tulsa, 179–206.

Higgins, G.E., and Saunders, J.B., 1974, Mud volcanoes: their nature and origin: Contribution to geology and paleobiology of the caribbean and adjacent areas: Verhandlungen Naturforschenden Gesellschaft Basel, **84**, 101–152.

Hong, W.L., Etiope, G., Yang, T.F., and Chang, P.Y., 2009. Methane micro-seepage in European and Asian mud volcanoes, submitted to the Journal of Asian Earth Sciences.

Huang, I.L., Teng, L.S., Liu, C.S., Reed, D.L., and Lundberg, N., 1992, Structural styles of offshore southwestern Taiwan: EOS, **73**, 539.

Kean, W.F., Walter, M.J., and Layson, H.R., 1987, Monitoring moisture migration in the vadose zone with resistivity: Groundwater, **25**, 562–571.

Keng, W.P., 1981, Geologic map of Tainan Hills: Bulletin of the Central Geological Survey, **1**, 1–31.

LaBrecque, D., Alumbaugh, D.L., Yang, Y., Paprocki, L., and Brainard, J., 2002, Three-dimensional monitoring of vadose zone infiltration using electrical resistivity tomography and cross-borehole ground penetrating radar *in* Three-dimensional electromagnetic Methods: Geochemistry and Geophysics 35, Zhdanov, M.S., and Wannermaker, P.E. (eds.), Elsevier Applied Science Publishers, Ltd., London, 260–272.

Liu, C.S., Huang, I.L., and Teng, L.S., 1997, Structural features off southwestern Taiwan: Marine Geology, **137**, 305–319.

Lippmann, E., 2005. Four-point light hp technical data and operating instructions ver. 3.37: Lipmann Geophysikalische Messgeräte, Schaufling, Germany, 29 pp.

Reed, D.L., Silver, E.R., Tagudin, J.E., Shipley, T.H., and Vrolijk, P., 1990, Relations between mud volcanoes, thrust deformation, slope sedimentation, and gas hydrate, offshore north Panama: Marine and Petroleum Geology, **7**, 44–54.

Shih, T.T., 1967, A survey of the active mud volcanoes in Taiwan and a study of their types and the character of the mud: Petroleum Geology Taiwan, **5**, 259–311.

Sung, Q.C., Chen, L., and Chen, Y.C., 2004, Some new observations about the Chishan Fault: Di-Chi, **23**, 31–40 (in Chinese).

Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1990, Applied Geophysics, 2nd ed.: Cambridge University Press, London, 860 pp.

Van, G.P., Park, S.K., and Hamilton, O., 1991, Monitoring leaks from storage ponds using resistivity methods: Geophysics, **56**, 1267–1270.

Wang, S., Shu, M., and Yang, C., 1988, Morphological study of mud volcanoes on land in Taiwan: Journal of Natural Taiwan Museum, **31**, 31–49.

Yang, C.H., Cheng, P.H., You, J.I., and Tsai, L.L., 2002, Significant resistivity changes in the fault zone associated with the 1999 Chi-Chi earthquake, west-central Taiwan: Tectonophysics, **350**, 299–313.

You, C.F., Gieskes, J., Lee, M.T., Yui, T.F., and Chen, H.W., 2004, Geochemistry of mud volcano fluids in the Taiwan accretionary prism: Applied Geochemistry, **19**, 695–707.

INTEGRATED GEOPHYSICAL INVESTIGATION FOR THE VULNERABILITY ASSESSMENT OF EARTHEN LEVEE

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Abstract

Integrated geophysical investigation was undertaken to assess the vulnerability of earthen levees to flooding and earthquake. The tested geophysical methods involved multi-channel surface wave dispersion measurement (MASW), capacitively coupled (CC) resistivity measurement, multi-frequency electromagnetic (EM) survey, and high-resolution seismic reflection survey using S-wave type Land Streamer. Because these methods required no fixing of sensors on the levee surface, high performance on field measurement work could be accomplished. The CC resistivity as well as EM survey successfully reconstructed resistivity profiles along levees, and delineated anomalously high or low resistivity zones within or beneath the levee body. The MASW method mapped shear wave velocity structures along levees, and clearly imaged relatively high or low velocity zones in the levee body. High-resolution seismic reflection surveying delineated the layered structure in the levee and in the underlying foundation sediments. Integrated investigations of resistivity and shear wave velocity structure remarkably highlighted the potentially permeable zones in the levee body as high resistivities and intermediate to low S-wave velocity areas. As a result, the geophysical methods effectively delineated the unexpectedly heterogeneous structure in the body of the levee, and the comprehensive investigation approach is shown to be helpful for the vulnerability assessment of levees through interpreting geophysical anomaly identified by means of integrated surveying.

Introduction

As a symbol of civilization, levee is one of the oldest man-made structures to protect farm lands and habitation areas from inundation by flood waters or to confine the stream flow to its regular channel. Actually, flood control through levee formation is still a high priority issue even for developed nations, as exemplified by the Hurricane Katrina disaster in 2005; or the Typhoon Tokage disaster, which struck the Japanese Islands in October 2004 with heavy rainfall and strong winds and caused 819 casualties along with about US$ 7.2 billion in economic loss.

Because most earthen levees have been repeatedly mounded and repaired for many years, their internal structure is generally inhomogeneous both in a lateral and a longitudinal direction in spite of their similar appearance as shown in **Fig. 1**. It can be easily imagined that the inhomogeneous structure would lead to the increase in failure potential of the levee body when attacked by flooding or by a strong earthquake. For instance, a part where earth materials were loosely stacked on an old body might have a potential risk of slipping at the boundary during an earthquake. Seepage potential may increase at the part where a new conduit or a box culvert was laid and backfilled after the open-cut due to uneven compaction of fill materials and resultant cavity initiation and growth adjacent the conduit.

Underlying layers also affect the stability of levee systems. For the case where the levee is built over buried stream channel segments, the paleo-channel deposits are usually soft and characterized as interbeds of sand and clay. Owing to their weak elastic properties and heterogeneity of permeability, the embankment over channel fill deposits has a potential of seepage and settlement. Irregular shape of buried topography under the alluvial plain would also cause the differential settlement of levee body.

Hence, it is very important to clarify the internal structure of levee body and underlying ground structure and to characterize their geotechnical properties for the vulnerability assessment of levee systems. Aerial photo analysis is helpful to map the old river system including paleo-channels, natural levees, point bars, and flood basins. However, it becomes difficult to identify such old river systems by means of aerial photo analysis with the formation age. Visual monitoring of levee surface and check drilling in spots has been a standard way for the safety investigation of levee in Japan. However these are incompetent for the evaluation of heterogeneous internal structure of levees. It has been therefore required to develop an effective, inexpensive and easy-to-apply field survey method which enables to delineate the internal structure of levee body and underlying layers continuously.

Geophysical methods are expected to play an important role in levee assessments. The physical properties provided by the various geophysical methods should be translated to practical criteria for judging levee safety. We started a comprehensive research project to develop effective geophysical methods for levee survey, and established the following three phases: Phase I objective is to develop continuous 2-D imaging techniques for identifying anomalies along the levee; the Phase II objective is to develop an approach for detailed investigations of anomalies identified in Phase I; and Phase III will directly investigate physical properties within the anomalous areas for the ground truth. As a part of Phase I research, we conducted field measurements of integrated geophysical surveying on earthen levees in Kanto Plain, central Japan (**Fig. 2**), and successfully delineated the internal structural heterogeneity in the levees as described below.

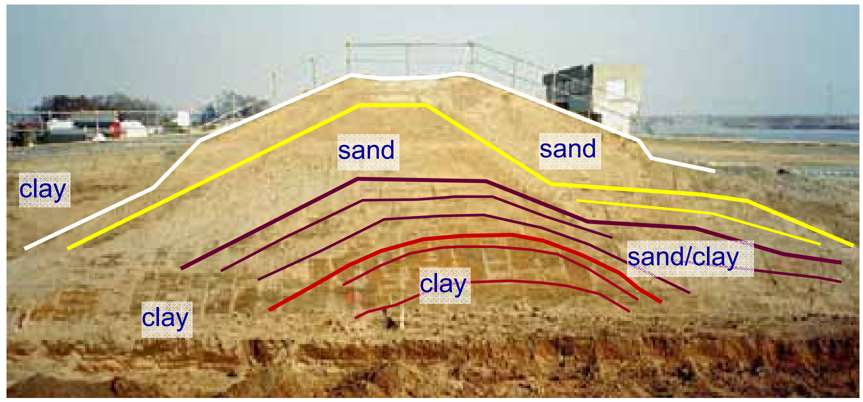

Figure1. A photo showing stacked structure in a levee body revealed at an open cut site.

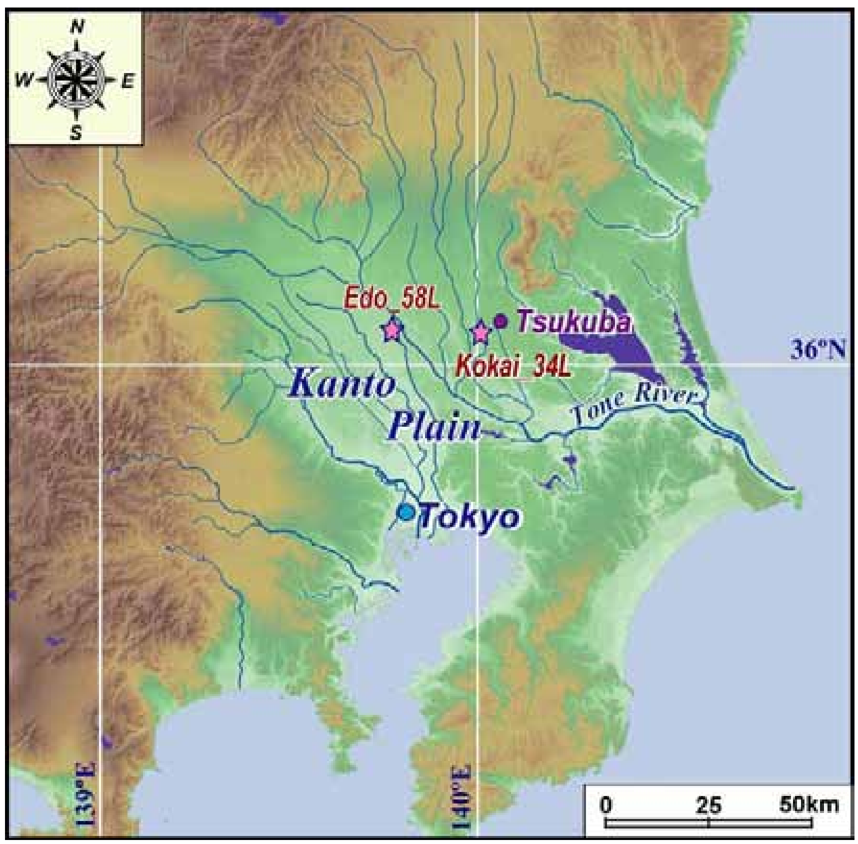

Figure 2. Map showing test sites. Integrated geophysical surveys were conducted on earthen levees along Edo and Kokai River, both are the branches of Tone River which flows through the Kanto Plain, central Japan.

Outline of geophysical methods applied to levee survey

The focused geophysical methods in our study were the seismic and resistivity methods. It was because of the well known relationship between shear wave velocities and soil stiffness, and between resistivity and soil permeability through grain size characteristics. We tested the geophysical survey methods as listed in **Table 1**. The tested methods consisted of multi-channel surface wave dispersion measurement (MASW), capacitively coupled (CC) resistivity measurement, multi-frequency electromagnetic (EM) survey, high-resolution seismic reflection survey using S-wave type Land Streamer, and conventional direct current (DC) resistivity survey. These methods were reviewed from the following viewpoints: (1) the method should be a non-destructive technique which does not cause any damage to levee; (2) the method provides a physical property helpful to evaluate the safety of levee; (3) the method should be a near-surface survey technique which can image shallow depths up to 20 m; (4) the method should have enough resolution to identify an anomaly as small as 10 meters; (5) the method provides a continuous profile along levee at affordable costs and high performance field work; and (6) the method should be technically transparent and open to be widely applied in levee survey.

Table 1. List of geophysical methods applied to levee survey

Method	Equipment	Property	Depths
MASW	Land Streamer	Vs	> 20m
CC Resistivity	OhmMapper	Resistivity	> 15m
EM	GEM-2	Conductivity	> 10m
Seismic Reflection	Land Streamer	Vs	> 50m
DC Resistivity	Steel Stake	Resistivity	> 20m

MASW method has been widely utilized to image near surface S-wave structure. Making use of Land Streamer tool (Inazaki, 1999), we could speed up the field performance of MASW survey (Hayashi, et al., 2003). In addition, a cross-correlation analysis (Hayashi & Suzuki, 2004) to common midpoint (CMP) gather data is effective to enhance the lateral resolution. We tested the method to determine if it had sufficient resolution and imaging depths.

Conventional DC resistivity surveys require planting electrode stakes into the ground, which is time-consuming and cumbersome work in the field. Recently, a new idea, which makes the transmitter and receiver to capacitively couple to the ground without planting galvanic electrodes, was proposed (Timofeev, et al., 1994) and became commercially available as OhmMapper. **Figure 3** shows a schematic diagram of the OhmMapper. A simple coaxial-cable array with transmitter and receiver sections is pulled along the ground either by a single person or attached to a small vehicle. Because a dataset is collected in a limited dipole-dipole configuration, the depth of investigation is varied by changing the separation between the transmitter and receivers or the length of dipole cables. Usually, multi-round survey is conducted along a line to acquire data enough to delineate the levee body. It is known that the CC resistivity method provides poor signals in an area where the near surface is

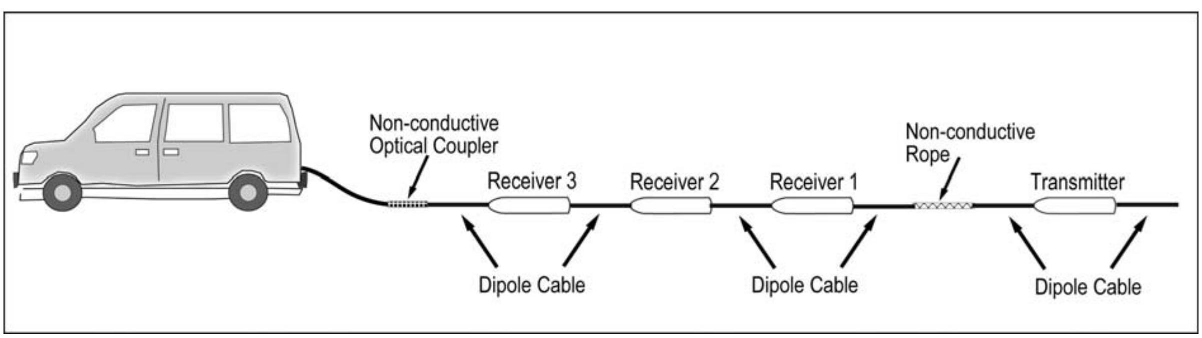

Figure 3. Schematic illustration of the OhmMapper tool.

conductive. It may be hard to image the internal structure of levees in case of high water or very wet condition. So we tested the method whether it was applicable to earthen levee by comparing it with the conventional DC resistivity survey results.

Electromagnetic (EM) methods have been commonly used to locate buried metal objects. Multi-frequency EM method generates sinusoidal electromagnetic signals from a few hundred Hz to above 20 kHz. Currents are induced in the ground at different depths as a function of the frequency. These currents then generate a secondary electromagnetic field, which is detected by the receiver coil after removing the influence of the primary field. We tested the GEM-2 (Huang & Won, 2003) as the EM tool for the continuous levee survey in the viewpoints of field performance, S/N, and mapping depths.

High resolution S-wave reflection method using Land Streamer tool was tested on levees to image internal structure of levee body and underlying layers. Although the tool can speed field work and provide a detailed image of near surface in contrast to those adopted in conventional shallow seismic reflection survey, the method might still have a problem on the performance or cost effectiveness to delineate the levee body. Then we conducted ultra-shallow reflection surveying using the short-spacing type Land Streamer (Inazaki, 2002) to test its applicability to the assessment of levee systems.

Integrated geophysical surveying on earthen levees

We have been conducting field measurements of integrated geophysical surveying on earthen levees at three sites, and successfully delineated the internal structural heterogeneity of the levees. The results at two sites positioned in **Fig. 2** are presented below.

Kokai_34L Site

Figure 4 shows the survey line set on earthen levee along the left side of Kokai River, a branch of Tone River, about 34 km upstream from the confluence. Kokai River flows southward through the eastern margin of Kanto Plain, and forms narrow alluvial lowland about 1 to 5 km in width along the river (**Fig.2**). Although it is as short as 112 km in length and the major part of its watershed is composed of plains, the river has been frequently overflowed. Indeed, the bank at opposite side of the surveyed site had broken in 1986. The flooding, started as seepage adjacent of a sluiceway, was followed by levee failure, and finally caused the inundation of farm land and habitation areas about 4,300 ha. The investigated levee is basically along the present channel, straightened through repeated improvements over the years, and crosses over abandoned channels at 35.0 and 34.2 km. There remains a small oxbow lake in the landside.

We set two major lines on the levee top; Kokai_32L100 and Kokai_34L100, length of the line was 1.6 km, and 1.9 km respectively. MASW and CC resistivity survey were conducted along the lines. In addition, multi-frequency EM, and shallow seismic reflection survey using Land Streamer were carried out along Kokai_34L100 line. Multi-channel GPR survey was also conducted along the line by other party (Yokota, et al., 2006). Furthermore we

Figure 4. Map showing the survey lines set on earthen levee along Kokai River, about 10 km west to PWRI.

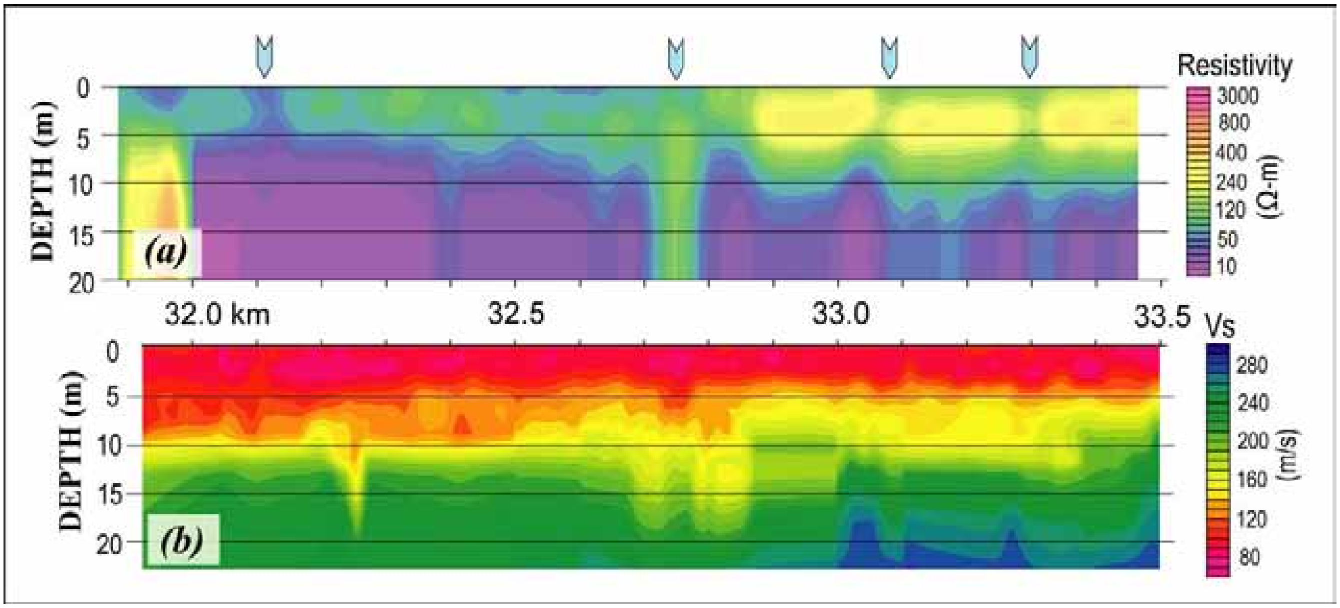

Figure 5. Comparison of survey profiles along Kokai_32L100 line. (a): Resistivity profile inverted from OhmMapper data. (b): S-wave velocity profile calculated from MASW survey data. Uppermost part down to 4 to 5 m deep corresponds to the levee body.

conducted ultra-shallow seismic reflection surveys using short-spacing type Land Streamer at the parts of Kokai_34L100 line.

Figure 5 compares the survey results along Kokai_32L line, from 31.9 to 33.5 km. Because the line was set on the levee crest, uppermost part down to 4 to 5 m deep corresponds to the levee body. As shown, the profiles clearly discriminate the levee body from underlying layers. The body is characterized as relatively high resistivity and low Vs zone. Note that the levee body shows high resistivity at the right half, which may indicate the difference in mounded periods or the filled materials. This is supported by a remark that the resistivity of levee body is lowered at the marked portions where ramps are connected to the levee embankment. It took only half a day by 3 crewmembers for the OhmMapper measurement, and the coverage speed of MASW measurement reached 800 m per day by 4 crewmembers at 2 m move-up condition.

The major survey profiles along Kokai_34L100 line are lined up in **Figure 6**. Figure 6(a) shows the response curves of quadrature components for 7 frequencies measured by means of GEM-2. Concave patterns at 34.4 and 35.3 km resulted from high-resistivity anomalies at the near surface. A surge superposed on the curve at 35.5 km is induced by the crossing over power lines. Generally, EM survey tends to be influenced by noises from the adjacent electric power line or such conductive objects as poles, manhole lids. In contrast, the survey speed is very high owing to the easiness of tool operation. Actually, it took only 2 hours for hand carry measurement to the line. Figure 6(b) is a resistivity profile along the line calculated from the OhmMapper data. Near surface part shallower than 6 m shows usually high resistivity, is interpreted as the levee body. Low resistivity zone below 6 m is correlated to the underlying alluvial sediments. Note that a portion younger than 34.1 km in distance shows relatively low resistivity even at the near surface. The line at the portion was on a river terrace and the near surface consists of clayey sediments of Pleistocene. The resistivity profile clearly distinguished the levee body from the natural ground. Another interest is the high resistivity anomalies identified in the near surface levee body at 34.4 and 35.3 km. These anomalies, occur also in high frequency curves in (a), may result from coarse sand parts or high permeable zones. Moreover, multi-channel GPR survey detected trough like structures in the levee body at the same portions. Figure 6(c) shows a shear wave velocity profile for

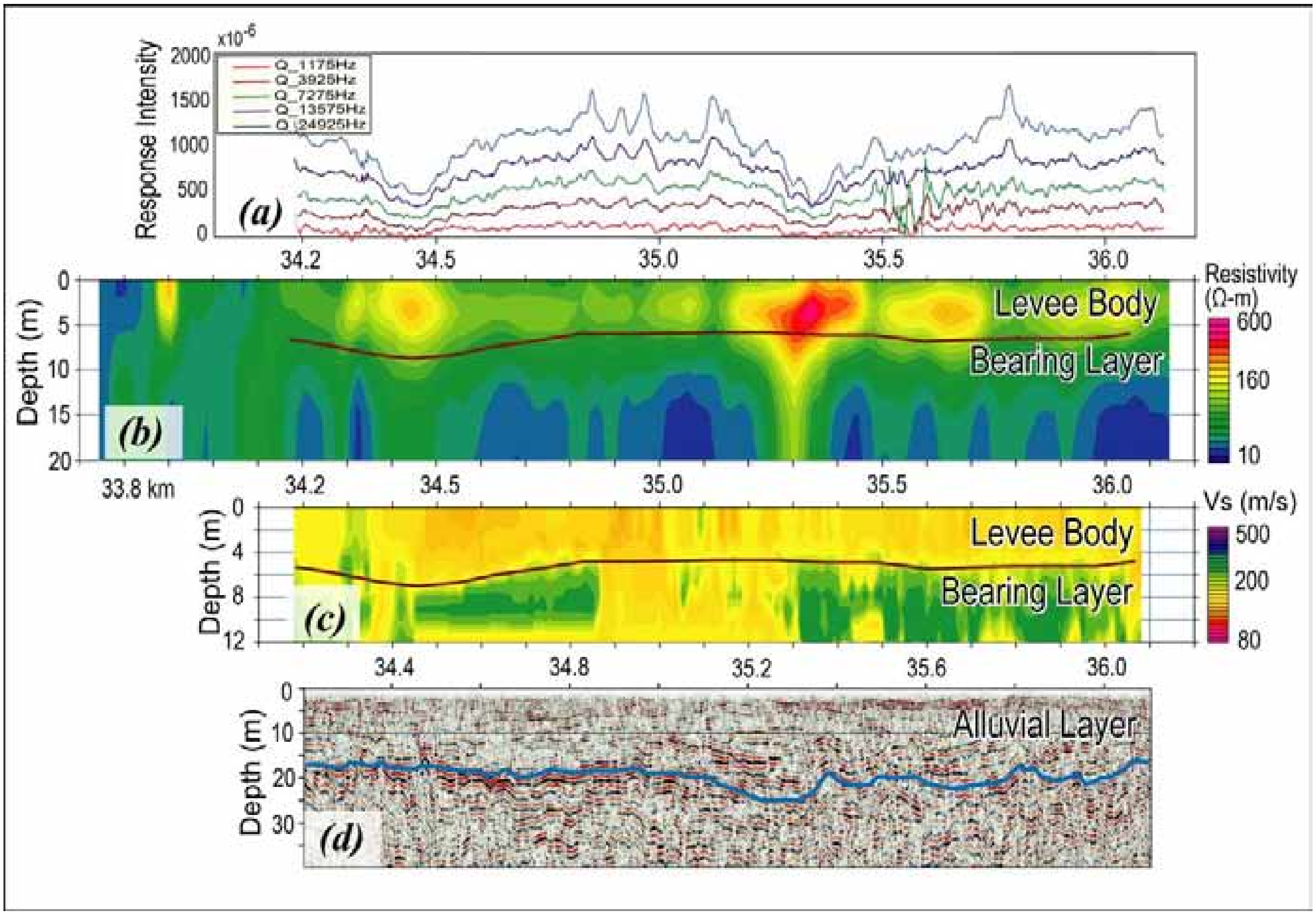

Figure 6. Comparison of survey profiles along Kokai_34L100 line. (a): Line plot of quadrature response for 7 frequencies measured using GEM-2. (b): Resistivity profile inverted from the data measured by means of OhmMapper. (c): S-wave velocity profile calculated from MASW data. (d): Stacked depth section reconstructed from the data of S-wave reflection survey using Land Streamer.

MASW data. The S-wave velocities at the uppermost part of the levee are about 140 m/s, which are moderate values as the levee materials. Compared with resistivity profile, S-wave velocities do not vary at the high-resistivity anomalies, which strongly indicate the anomalies are not due to abandoned or buried concrete blocks but due to unsaturated coarse grained materials. Profiles of high-resolution seismic reflection surveys making use of S-wave Land Streamer are shown in Fig, 6(d). The profiles clearly delineated the bottom of alluvial soft sediments at about 20 m in depth. The imaging depths of reflection survey may too deep for the levee assessment, but note that the profile identified a buried channel at 35.2 km where the levee just pass over an abandoned channel. This irregular structure in the bearing layers may lead to uneven settlement of levee system.

Edo_58L site

Figure 7 shows Edo_58L site where a survey line was set on an earthen levee along the left side of Edo River. The Edo River branches off from Tone River at the survey site, and flows into Tokyo Bay through the Tokyo Metropolitan area **(Fig.2)**. Edo River, as shown in its name, was extensively improved in Edo Era about 400 years ago to develop navigation network around the capital city Edo as well as to prevent the city area from flooding. Because the stream at the site had been excavated as a shortcut across original meandering channels, abandoned channels or fragments of old bank were estimated to be buried beneath the present levee.

A resistivity profile and an S-wave velocity profile along the line are shown in **Figure 8**, determined from the OhmMapper and MASW data, respectively. As clearly shown, a high resistivity anomaly was delineated at the portion from 57.8 to 58.4 km, whereas the S-wave velocities at the anomaly were not so high. The high resistivity anomaly is characterized that it occurs in the underlying layers and can be traced at least 10 m in depth. This is distinctly different from that of Kokai_34L site. The mode of occurrence of the anomaly strongly suggests it is a remnant of an old town which had been covered by the levee system about 40 years ago. The levee body, corresponds to the top 5 m, is featured as relatively low resistivity and low Vs in the profile.

Figure 7. Map showing Edo_58L site along the left side levee of Edo River, about 50 km north to Tokyo.

Conclusions

Integrated geophysical surveys were conducted on earthen levees to establish the helpful geophysical methods for levee safety assessment. We chose the following three methods, namely, MASW, CC resistivity, and multi-frequency EM, because of their high field performance along with advantages to provide useful geophysical properties, resistivity and shear wave velocity, for the vulnerability assessment of levee systems. It is well known that shear wave velocities has close relation with soil stiffness, and resistivity with soil permeability through grain size characteristics.

We tested above methods at two sites. As a result, we could verify the advantages of field work, resultant cost

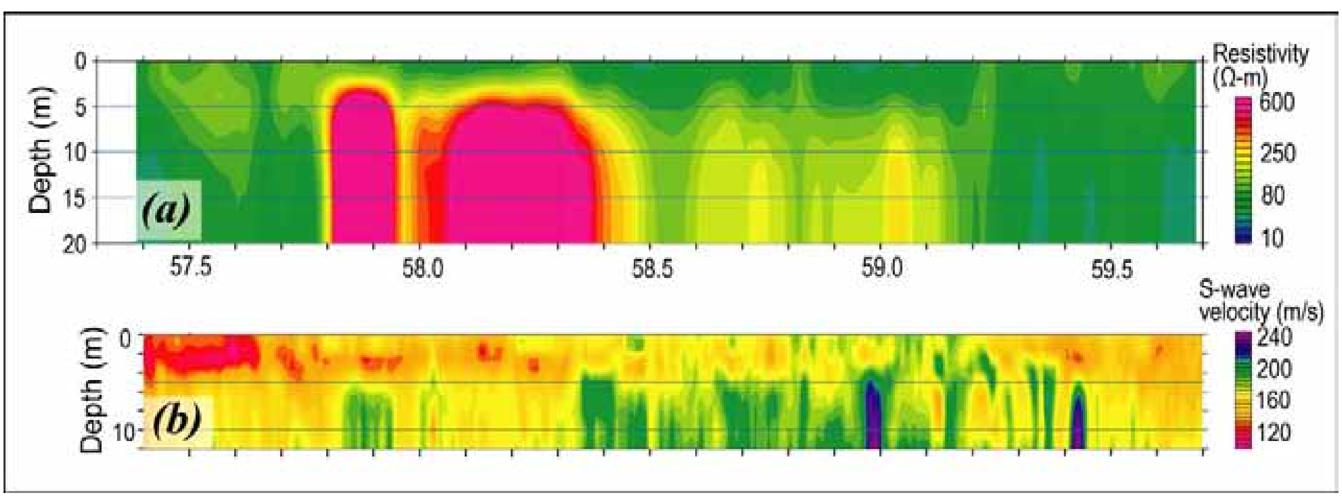

Figure 8. A resistivity (a) and S-wave velocity (b) profile along the levee at Edo_58L site. A high resistivity anomaly was delineated at the portion from 57.8 to 58.4 km, whereas the S-wave velocities at the anomaly were not so high. The upstream part of the line (59.2 to 59.7 km) showed relatively low resistivity and relatively low S-wave velocity.

effectiveness, and detection capability of anomaly. Actually, CC resistivity and multi-frequency EM surveys showed high coverage speed about 2 km per half a day only by one or two crewmembers. Coverage speed for MASW survey was about 800 m per day by 4 crewmembers. We could easily discriminate levee body with underlying sediments in the profiles provided by these surveys, and successfully identify anomaly structure in and beneath levees. Because the size of our target anomaly is several 10 meters to several 100 meters, it is needful to set the survey line at least 1 km along levee. In conclusion, combination measurement of CC resistivity or multi-frequency EM method with MASW method is recommended for the assessment of failure potential of levee. The geophysical properties obtained by these measurements, resistivity and shear wave velocity, is essential to interpret levee body materials, and to evaluate the permeability and stiffness of levee body.

Acknowledgements

The author wishes to thank Dr. K. Hayashi of OYO Corporation for his field supports and data analysis. I would like to express my sincere condolences to late Hide Miura of Terra Corporation for his continual support and empathetic cooperation to my research work. The author also gratefully acknowledges Mr. Y. Morita and K. Watanuki of Shimodate River Office, and Mr. Y. Mashimo of Edogawa River Office, who afforded many conveniences to conduct field work and provided useful data for this research.

References

Hayashi, K., Okada, S., Suzuki, H., and Inazaki, T., 2003, A surface wave method using Land Streamer, *Proceedings of the 108th SEGJ Conference*, p298-301. (*in Japanese*)

Hayashi, K. and Suzuki, H., 2004, CMP cross-correlation analysis of multi-channel surface-wave data, *Exploration Geophysics*, **35**, p7-13.

Timofeev, V. M., Rogozinski, A. W., Hunter, J. A. and Douma, M., 1994, A new ground resistivity method for engineering and environmental geophysics, *Proceedings of the 7th Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP1994)*, p701-715.

Huang, H. and Won, I. J., 2003, Real-time resistivity sounding using a hand-held broadband electromagnetic sensor. *Geophysics*, **68**, p1224-1231.

Inazaki, T., 1999, Land Streamer; a new system for high-resolution S-wave shallow reflection surveys, *Proceedings of the 12th Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP1999)*, p207-216.

Inazaki, T., and Sakamoto, T., 2005, Geotechnical characterization of levee by integrated geophysical surveying, *Proceedings of the International Symposium on Dam Safety and Detection of Hidden Troubles of Dams and Dikes*, CD-ROM, 8p.

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Pile Dynamics, Inc. develops breakthrough test for concrete foundations in partnership with FGE

Gina Beim, Pile Dynamics, Cleveland, OH (www.pile.com)

A new solution for integrity evaluation of concrete foundations has been developed by the Pile Dynamics (PDI) - Foundation & Geotechnical Engineering, LLC (FGE) partnership: the Thermal Integrity Profiler (TIP).

TIP uses the heat generated by curing cement (hydration energy) to assess the quality of cast in place concrete foundations such as drilled shafts, bored piles, augered cast-in-place, continuous flight auger piles and drilled displacement piles. Because temperatures within the concrete foundation are dependent on its diameter and distance to the center of the shaft, TIP measurements may be used to estimate the actual shape of the shaft including the previously difficult to determine thickness of concrete cover.

The Thermal Integrity Profiler, which is based on research conducted at the University of South Florida and originally implemented by FGE, is attractive in that it assesses the concrete quality of the entire cross-section and along the entire length of the foundation. Another major advantage of the TIP is its early testing time; test results are available as early as 12 hours after concrete is poured, allowing construction to continue.

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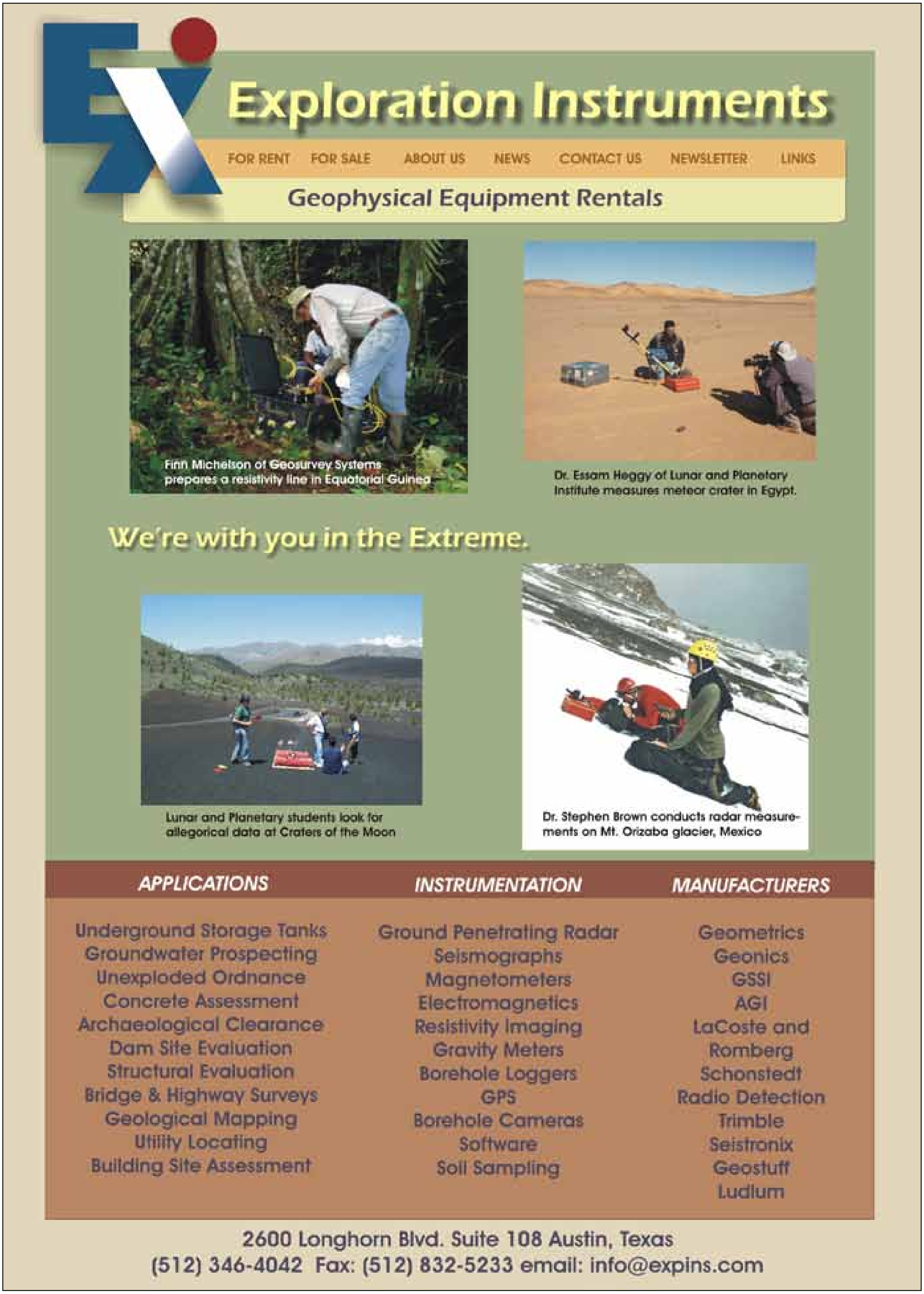
In addition to the Thermal Integrity Profiler, Pile Dynamics produces several other quality assurance and quality control products for the deep foundations industry. Its products are recognized throughout the world as the ultimate solutions for testing and monitoring of deep foundations. The company is based in Cleveland OH and has commercial representatives worldwide.

FGE – Foundation and Geotechnical Engineering LLC – is based in Plant City, FL and specializes in deep foundation design, capacity enhancement, rehabilitation/remediation and quality assurance/verification testing.

For more information on the Thermal Integrity Profiler visit www.pile.com/pdi/products/TIP.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SERDP & ESTCP to Host Annual Technical Symposium & Workshop

November 29 – December 1, 2011

The Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) will hold the annual Partners in Environmental Technology Technical Symposium & Workshop, "Meeting DoD's Environmental Challenges," at the Washington Hilton in Washington, D.C. This nationally recognized conference focuses on the Department of Defense's (DoD) priority environmental issues. The approximately 1,200 attendees span the military Services; academic and research institutions; private sector technology and environmental firms; and Federal, state, and local regulatory and policy making organizations.

This year's Symposium & Workshop will offer a dynamic opening Plenary Session, 15 technical sessions, four short courses, and more than 450 technical poster presentations, and exhibitors from funding and partnering organizations. Technical sessions will highlight research and innovative technologies that assist DoD in addressing increasingly complex environmental and mission sustainability challenges. Short courses on select technologies and alternative approaches in the environmental restoration and munitions response areas will offer unique training on recent advances in science and technology.

Technical Sessions: This year's technical program offers sessions on the topics below.

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- Environmental Molecular Diagnostic Tools: Innovations and Applications
- Improving Our Understanding of the Impact of Contaminants Stored in Low Permeability Zones
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- Classification Applied to Munitions Response – Development
- Classification Applied to Munitions Response – Production Applications
- National and International Regulatory Impacts on DoD Operations: Refining the Goals of DoD's Strategic Plan for 'REACH'
- Next Generation Energetic Materials – Striking a Balance between Performance, Insensitivity, and Environmental Sustainability
- Impact of Particulate Emissions from Gas Turbine Powered Aircraft

Short Courses: Four short courses will be offered for which Professional Development Hours will be available! Attendance for these courses will be limited, and space will be available on a first-come first-serve basis. Therefore, registration for each short course will be required for you to attend. Below are this year's short courses.

- Estimating DNAPL Source Zone Natural Attenuation
- Thermal Treatment Technologies: Lessons Learned
- Implementing Classification on a Munitions Response Project
- Field Methods to Distinguish between Vapor Intrusion and Indoor Sources of VOCs

For additional information, please visit www.serdp-estcp.org/symposium, send an e-mail to partners@hgl.com, or call the Symposium Contact Line at (703) 736-4548.

The EEGS / Geonics Early Career Award

Nomination Deadline – October 29, 2011

The Environmental and Engineering Geophysical Society and Geonics Limited are pleased to announce that nominations are now open for the 2012 EEGS / Geonics Early Career Award, which acknowledges academic excellence and encourages research in near-surface geophysics. The award is presented annually at SAGEEP to a full-time university faculty member who, by the nomination deadline is:

- fewer than five years beyond the starting date of his or her current academic appointment;
- within ten years post-completion of his or her PhD.

The award acknowledges significant and ongoing contributions to the discipline of environmental and engineering geophysics. The recipient may have any specialty that is recognized as part of the environmental and engineering geophysics discipline. This specialty is not restricted to departments, colleges, or geographic regions (international applicants are welcome). A committee of four or five members (two or three university faculty, one corporate or consulting representative, and one government laboratory representative), appointed by the EEGS Board, is responsible for selecting the awardee.

The award carries the following benefits:

- Free registration to the SAGEEP conference at which the award will be presented
- A plaque, suitable for display
- A $1000 cash award
- A 30-minute time slot to present the awardee's research and vision at SAGEEP
- The citation and, if available, the awardee's presentation, is published in FastTIMES and distributed to cooperating societies

The awardee will be expected to be present during the technical core of SAGEEP 2012 in Tuscson, Arizona. Nominations should be sent electronically to:

Dr. Jonathan Nyquist
Chair of the Early Career Award Committee
Temple University
1901 N 13th Street, Philadelphia, PA 19122-6081
Phone: 215-204-7484
nyq@temple.edu

Nomination packages must include:

- A comprehensive vitae for the candidate
- A letter of recommendation outlining the candidate's qualifications for the award
- Copies or pdf files of three representative publications

Call for Papers: Special Issues in EAGE journal of Near Surface Geophysics and EEGS Journal of Environmental and Engineering Geophysics (JEEG)

Deadline for submission of abstracts: 15 October 2011

The past decade has seen a distinct change in the way geophysical methods are utilized to investigate geotechnical and geoenvironmental issues. Advances in instrumentation design, computer hardware and data processing software have all contributed to the development of novel and highly sophisticated geophysical techniques. In response to this rapid and exciting expansion of research, the Journal of Environmental and Engineering Geophysics and Near Surface Geophysics are producing a collaborative 'Special Issue on Geotechnical Assessment and Geoenvironmental Engineering' to showcase the state-of-the-art and the most pertinent research currently underway in the discipline.

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__FastTIMES__ highlights upcoming events of interest to the near-surface community. Send your submissions to the editors for possible inclusion in the next issue.

The 10th SEGJ International Symposium

Imaging and Interpretation

November 20-23, 2011, Kyoto, Japan

The Society of Exploration Geophysicists of Japan (SEGJ) observes its vicennial anniversary in Kyoto at the Centennial Memorial Hall of Kyoto University. Under the theme "Imaging and interpretation", the Symposium's technical program presents the latest scientific and technological advances related to a broad range of geophysical applications that are used to better understand and model invisible underground structures and processes in various environmental and engineering investigations. For more information, please visit the symposium website (*http://www.segj.org/is/10th*) or contact Professor Hitoshi Mikada, General Chair at *segj10th@segj.org*.

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March 25-29, 2012, Tucson, Arizona

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	0012	1988-2000 (CD-ROM)	$150	$225
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	0027	Principles and Applications of Seismic Refraction Tomography (Printed Course Notes & CD-ROM) - William Doll	$125	$150
	0028	Principles and Applications of Seismic Refraction Tomography (CD-ROM including PDF format Course Notes) - William Doll	$70	$90
	0007	2002 - UXO 101 - An Introduction to Unexploded Ordnance - (Dwain Butler, Roger Young, William Veith)	$15	$25
	0009	2001 - Applications of Geophysics in Geotechnical and Environmental Engineering (HANDBOOK ONLY) - John Greenhouse	$25	$35
	0011	2001 - Applications of Geophysics in Environmental Investigations (CD-ROM ONLY) - John Greenhouse	$80	$105
	0010	2001- Applications of Geophysics in Geotechnical and Environmental Engineering (HANDBOOK) & Applications of Geophysics in Environmental Investigations (CD-ROM) - John Greenhouse	$100	$125
	0004	1998 - Global Positioning System (GPS): Theory and Practice - John D. Bossler & Dorota A. Brzezinska	$10	$15
	0003	1998 - Introduction to Environmental & Engineering Geophysics - Roelof Versteeg	$10	$15
	0002	1998 - Near Surface Seismology - Don Steeples	$10	$15
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	0005	1997 - An Introduction to Near-Surface and Environmental Geophysical Methods and Applications - Roelof Versteeg	$10	$15
	0006	1996 - Introduction to Geophysical Techniques and their Applications for Engineers and Project Managers - Richard Benson & Lynn Yuhr	$10	$15

Miscellaneous Items

	0021	Geophysics Applied to Contaminant Studies: Papers Presented at SAGEEP from 1988-2006 (CD-ROM)	$50	$75
	0022	Application of Geophysical Methods to Engineering and Environmental Problems - Produced by SEGJ	$35	$45
	0019	Near Surface Geophysics - 2005 Dwain K. Butler, Ed.; Hardcover Special student rate - 71.20	$89	$139
	0024	Ultimate Periodic Chart - Produced by Mineral Information Institute	$20	$25
	0008	MATLAB Made Easy - Limited Availability	$70	$95
		EEGS T-shirt (X-Large) Please circle: white/gray	$10	$10
		EEGS Lapel Pin	$3	$3
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	1998				JEEG 8/3 - September			JEEG 12/2 - June
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		JEEG 3/3 - September		**2004**				JEEG 12/4 - December
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