FastTIMES

March 2009
Volume 14, Number 1
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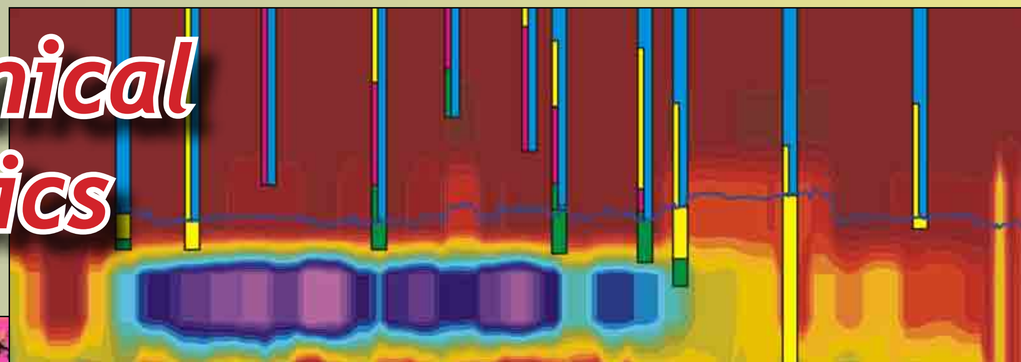
Magazine for the Near-Surface Geophysical Sciences

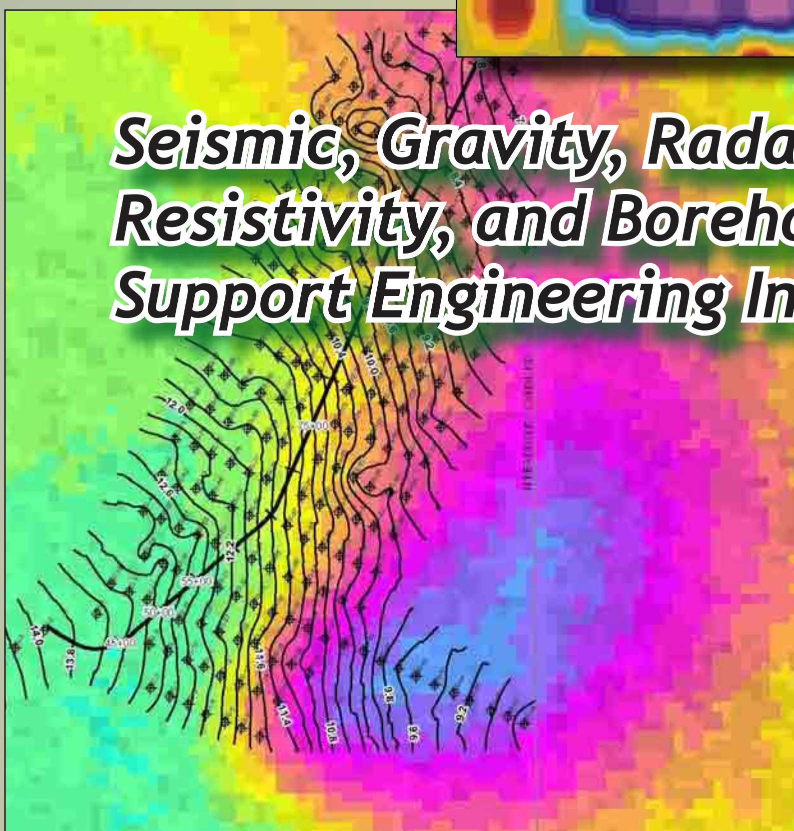
Published by the Environmental & Engineering Geophysical Society

Geotechnical Geophysics

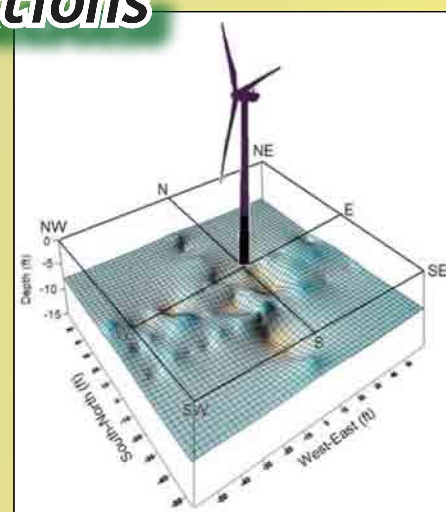


Resistivity at the Panama Canal

Seismic, Gravity, Radar, Resistivity, and Borehole Methods Support Engineering Investigations



Radar interferometry and gravity for dam safety

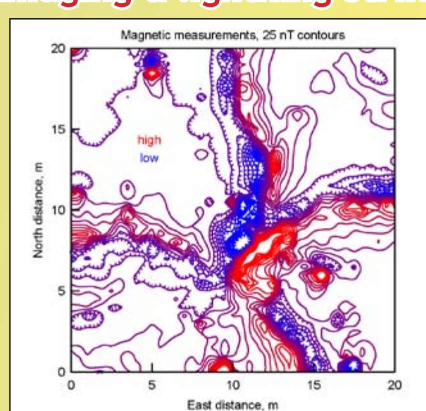


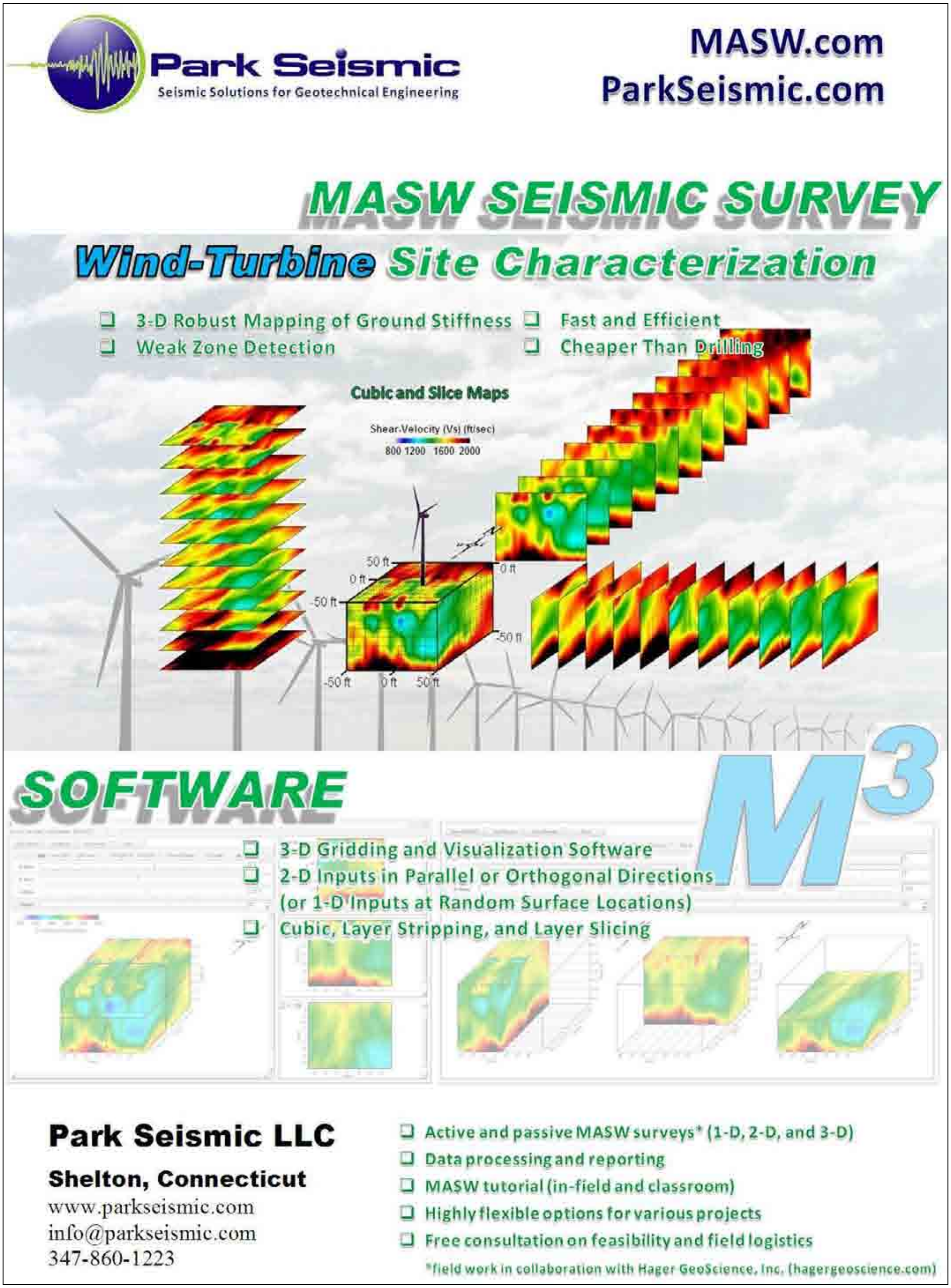
Surface waves for wind power

Also in this issue . . .

- Magnetic signature of a lightning strike
- Borehole geophysics and slope stability
- Assessing deep-mine hazards with radar
- Invitation to SAGEEP 2009, Fort Worth
- Near-surface highlights at the Fall AGU
- Online availability of ASEG publications

Imaging a lightning strike

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On the Cover

Myriad geophysical methods have been applied to geotechnical studies, offering minimally invasive information supporting design, construction, hazard assessment, and remediation. **Lower left:** gravity contours superimposed on radar interferogram to assess dam safety in Arizona (article on p. 33). **Upper right**: marine resistivity data from the Panama Canal (article on p. 43). **Lower right**: bedrock topography from surface-wave data at a wind-turbine site in the midwestern U.S. (article on p. 17). **Far lower right**: magnetic-field image at a lightning-strike site in northwest Wales (article on p. 61).

What We Want From You

The ***FastTIMES*** editors appreciate most any geophysical contribution. Suggestions for the June 2009 issue include the role of geophysics in abandoned-mine investigations. We also welcome photographs and brief noncommercial 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 May 21, 2009 to ensure inclusion in the next issue.

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Fort Worth is filled with culture and western heritage and has much to offer: the historical stockyards, great museums, exciting downtown, wonderful restaurants, and fun nightlife. If there's one meeting you schedule for the year, SAGEEP 2009 should be the one. Why?

Short Courses - Surface Waves are for Everyone, **Borehole Geophysical Techniques for Groundwater and Environmental Applications**, **The Art and Science of GPR - Expanded**, and **Principles and Applications of Seismic Refraction Tomography**.
For details, click http://www.eegs.org/sageep/courses.html. (Some begin on Saturday, March 28!)

SAGEEP 2009 Outdoor Demo Round Up - Demonstrations of state-of-the-art geophysical equipment and techniques will being held in the Stock Yards area at Billy Bob's Texas!

Strong Technical Program—New this year: Special Student Session, Session Keynotes and Special Sessions. **Session Keynote** titles: **Odysseus Unbound: Geophysics in the Search for Homer's I**thaca; **The Self-Potential Method: Did the Ugly Duckling of Environmental Geophysics Become a Beautiful Swan**?; **The "Nuclear Renaissance" and its Implications for Geophysics**; **Robust, Broadband Finite Difference Time Domain Modeling of EM Propagation in the Subsurface**; **Soil Magnetism Research: State of the Art and Future Directions.**

Field Trips - two this year: a guided SEGWAY tour and a walking tour, including lunch, of the Trinity River Project in downtown Fort Worth. And, the **SAGEEP Conference Evening Event -** Good music, drinks, food in the historic Ashton Train Depot **-** this night offers that chance to relax and enjoy the camaraderie with old friends and colleagues...and new ones!

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 student membership with a ***JEEG*** subscription ($20 without ***JEEG)***, and $650 to $3750 for various levels of corporate membership. The membership application is available at the back of this issue, from the EEGS office at the address given below, or online at www.eegs.org. See the back for an explanation of membership categories.

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The next ***FastTIMES*** will be published in June 2009. Please send articles to a member of the editorial team by May 21. Advertisements are due to Jackie Jacoby by May 21.

Calendar

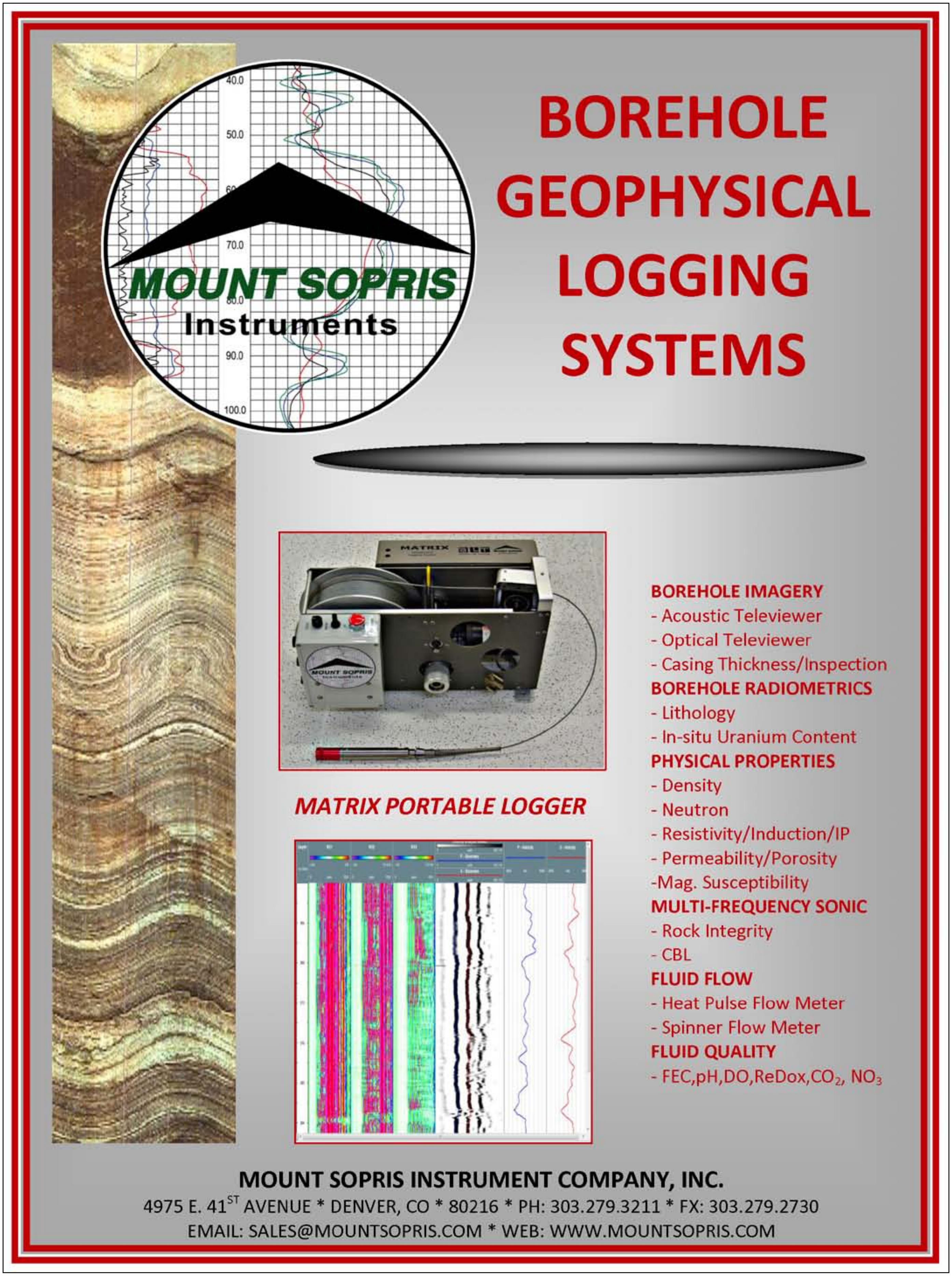
*Please send additions, errors, and omissions to a member of the **FastTIMES** editorial team.*

2009

March 15–19	International Foundation Congress and Equipment Exhibition, Lake Buena Vista, Florida
March 29–April 2	22nd SAGEEP, Fort Worth, Texas
April 19–23	NGWA 2009 Ground Water Summit, Tucson, Arizona
May 11–14	34th Southwest Geotechnical Engineers Conference, Phoenix, Arizona
May 24–27	2009 Joint Assembly, Toronto, Ontario, Canada
August 16–19	AAPG/SEG/SPE Hedberg Research Conference, Geological Carbon Sequestration: Prediction and Verification, Vancouver, British Columbia
September 7–9	Near Surface 2009: 15th European Meeting of Environmental and Engineering Geophysics, Dublin, Ireland
September 7–11	ISEG 2009: 10th Symposium on Environmental Geotechnology and Sustainable Development, Bochum, Germany
October 12–14	9th Symposium, Society of Exploration Geophysicists of Japan, Sapporo, Japan
October 18–21	Geological Society of America Annual Meeting, Portland, Oregon
October 25–30	SEG International Exposition and 79th Annual Meeting, Houston, Texas

2010

September 5–10	IAEG 2010: 11th Congress of the International Association for Engineering Geology and the Environment, Auckland, New Zealand



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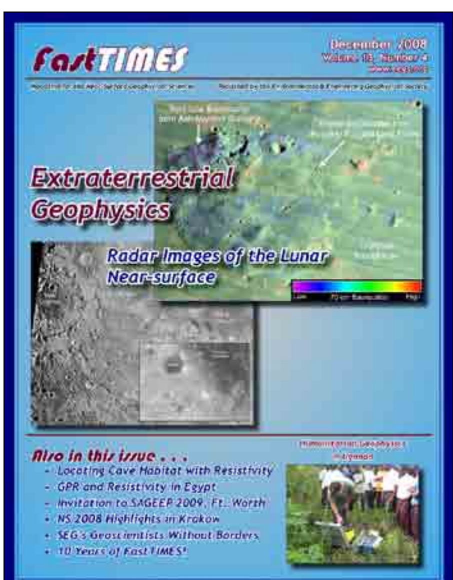
President's Message: The Power of Geophysics

Jonathan Nyquist, President (nyq@temple.edu)

My first taste of field geophysics came as a graduate student at the University of Wisconsin, Madison in the Antarctic Research Program. Our field crew was dropped on top of Ice Stream B in the West Antarctic Ice Sheet. The goal was to figure out why ice streams, which account for about 10 percent of the total ice volume, move so quickly – up to a kilometer per year – relative to the rest of the ice sheet. The tools included seismic refraction and reflection, ground (ice) penetrating radar, electrical resistivity, gravity and magnetics. As a novice member of the field crew I had such exciting jobs as hustling resistivity electrodes, and wiring nitrocarbonitrate seismic charges in the freezing cold, while the more senior graduate students sat in the nice, warm instrument hut monitoring the incoming data. Despite the inglorious tasks, I was captivated by the power of geophysics to image the bottom of an ice sheet thousands of meters thick.

I eagerly anticipate SAGEEP each year because I remain captivated by the power of geophysics, and there is no better place to share in the knowledge of experienced geophysicists and engineers. Each talk, each poster, takes you to a different part of the world, confronts you with a different imaging challenge, and offers a new solution. Always, I return home from SAGEEP feeling renewed, bubbling with new ideas, and armed with a list of new constants for future collaboration. When financial times are tight, travel budgets are often the first casualty. But I cannot afford to miss SAGEEP, and neither can you. It is a pleasure you owe yourself as a professional. Time is short, so now is the time to register and make your reservations if you have not already done so.

Oh, and what was the explanation for Ice Stream B's rapid rush to the sea? I will tell you when I see you in Fort Worth!



From the FastTIMES Editorial Team

FastTIMES is distributed as an electronic document (pdf) to all EEGS members, is sent by web link to several related professional societies, and is available to all for download from the EEGS web site at www.eegs.org/fasttimes/latest.html. The most recent issue (December 2008, cover image at left) has been downloaded more than 10,500 times through February, 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

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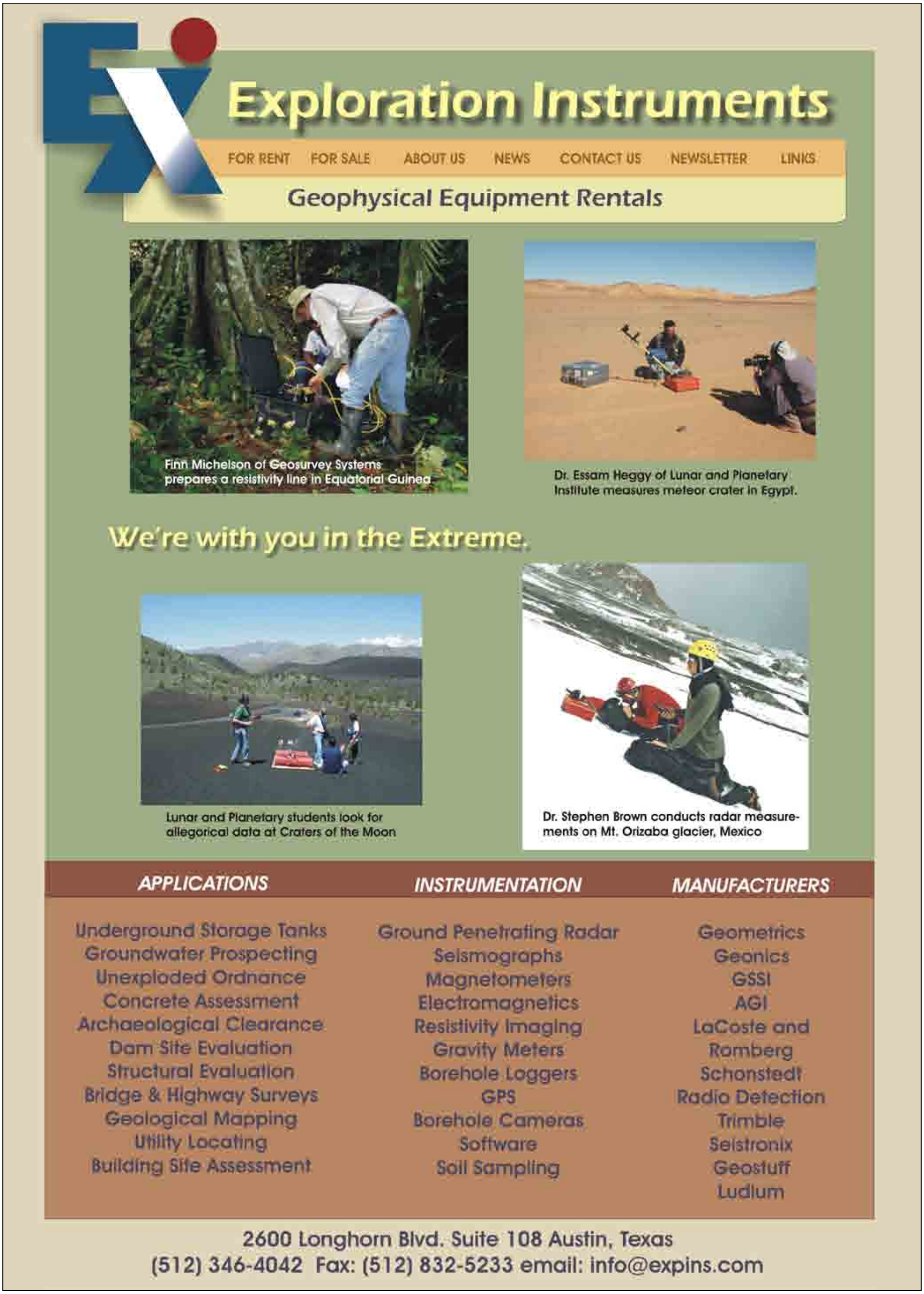
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geophysics, whether you are an EEGS member or not. We welcome short research articles or descriptions of geophysical successes and challenges, summaries of recent conferences, notices of upcoming events, descriptions of new hardware or software developments, 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.

From the (Outgoing) Editor

Jeffrey G. Paine (jeff.paine@beg.utexas.edu)

It was the Fall 2006 EEGS board meeting in Denver when I volunteered to be "temporary" editor of ***FastTIMES*** to help shepherd its transition to an electronic-only publication. I was President Elect at the time, and felt that ***FastTIMES*** could and should serve as a primary means of disseminating societal and technical information to the EEGS membership, the larger near-surface geophysics community, and even non-geophysicists who might have an interest in how geophysics is applied to near-surface issues in the broadest sense. Ten issues and more than two years down the road, I can honestly say that I've enjoyed my time as editor and some progress has been made. ***FastTIMES*** has grown to become a magazine shared by the entire near-surface community. The number of articles and overall page count has grown significantly, and with that content expansion has come growth in readership. ***FastTIMES*** routinely reaches 10,000 downloads per issue, not just to EEGS members but to members of many other international societies devoted to geophysics and served by geophysicists. Along the way, the ***FastTIMES*** web presence has been updated to better disseminate current and past issues to those who would like to read them. ***FastTIMES*** now has an ISSN (International Standard Serial Number), an international identification code for serial publications. It's been fun putting together each issue, corresponding with article authors and individuals from other societies, and watching the download numbers grow issue by issue. Of course, none of these accomplishments would have been possible without the assistance of Jackie Jacoby at the EEGS business office and the editorial team of Roger Young, Brad Isbell, and Moe Momayez.

Now it's time to pass the responsibility to a real editor. With the upcoming June issue, Moe Momayez will begin his term as Editor-in-Chief. Moe is an Associate Professor in the Department of Mining and Geological Engineering at the University of Arizona and has been serving as an Associate Editor since November. Moe specializes in the development and application of near-surface sensing technologies to characterize geomaterials in soil and rock mechanics, structural stability, site characterization, and mine planning investigations. Please help make Moe's job easier by continuing to send articles, news of upcoming events, opportunities, reports of recent events, and any other items of interest to the near-surface geophysics community. Thank you all for reading and contributing to ***FastTIMES*** over the last two years!

Renew your EEGS Membership for 2009 (You Can Do It Online)!

Be sure to renew your EEGS membership for 2009! In addition to the more tangible member benefits (including a print 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 serving SAGEEP papers from the EEGS web site and support for the 2010 SAGEEP conference to be held in the Denver area. Contact Jon Nyquist (*nyq@temple.edu*) for more 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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Journal of Environmental & Engineering Geophysics

March 2009 Volume 14 Issue 1

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The Environmental and Engineering Geophysical Society

Journal of Environmental & Engineering Geophysics v. 14, no. 1, March 2009

Editor's Scratch

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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.

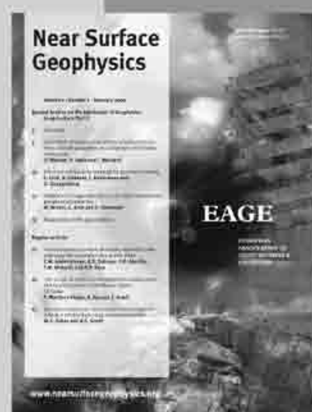
EAGE's Near Surface Geophysics Journal, February 2009

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 February issue of EAGE's* ***Near Surface Geophysics*** *journal.*

ALSO INTERESTING

Near Surface Geophysics

Volume 7 · Number 1 · February 2009



Content

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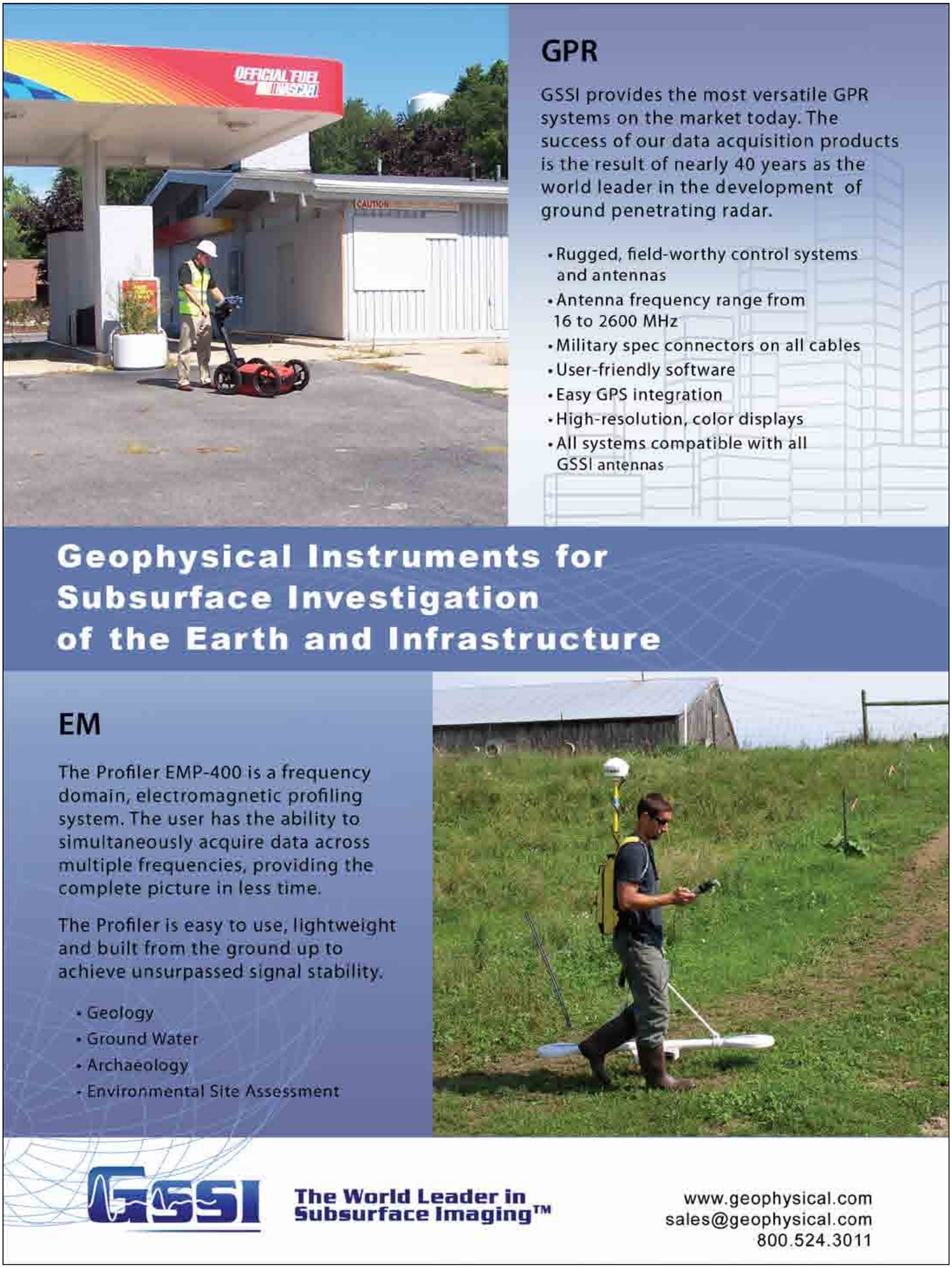

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FastTIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, soil science, hydrology, archaeology, and astronomy. In the articles that follow, the authors illustrate how noninvasive geophysical methods have been applied to a variety of geotechnical problems. A bonus article investigates the magnetic signature of a lightning strike.

Wind Turbine Site Characterization by Seismic (MASW) Method

by Choon B. Park, Park Seismic LLC, Shelton, Connecticut (choon@parkseismic.com)

Introduction

Wind energy in the U.S. grew by record 8,300 Megawatts (MW) in the year of 2008, enough energy to serve over two million homes (the turbine shown in Figure 1 generates about 1.7 MW). This industry channeled an investment of over $17 billion into the U.S. economy, positioning wind power as one of the leading sources of new power generation in the country today along with natural gas, according to the recent statistics announced by the American Wind Energy Association (AWEA) (www.awea.org). This swelling in investment parallels the recent global trend in green investment (Figure 1). With the new U.S. presidential administration, it seems the trend will only accelerate.

This rapid expansion of wind energy worldwide has also given rise to the demand to use new technologies to make construction of a turbine site more robust and cost effective. Recently, a seismic approach — the multichannel analysis of surface waves (MASW) method (Park and others, 1999) — has been applied to site characterization efforts to replace (or reinforce) the conventional drilling approach at several places in the west and midwest United States. The first wind turbine site characterization by the MASW method was reported by Park and Miller (2005a; 2005b) following its successful application at eighty-four proposed turbine sites in the second phase of construction of the Blue Canyon Wind Farm (Park and Miller, 2005a) (Figure 2) near Lawton, Oklahoma, plus twenty sites near Elk River in Kansas (Park and Miller, 2005b). It seems this type of seismic characterization is rapidly spreading to other places, including Texas, New Mexico, and California.

Figure 1. Relatively large wind turbines and the global green investment in the year 2008.

Dynamic Property of Wind-Turbine Site

A wind-turbine site has special characteristics that must be considered before and during construction of the tower. The heavy weight of the tower structure is built on a relatively small area on the ground (15 x 15 m, for example) (Figure 3). Following construction, the ground volume below and around the tower will

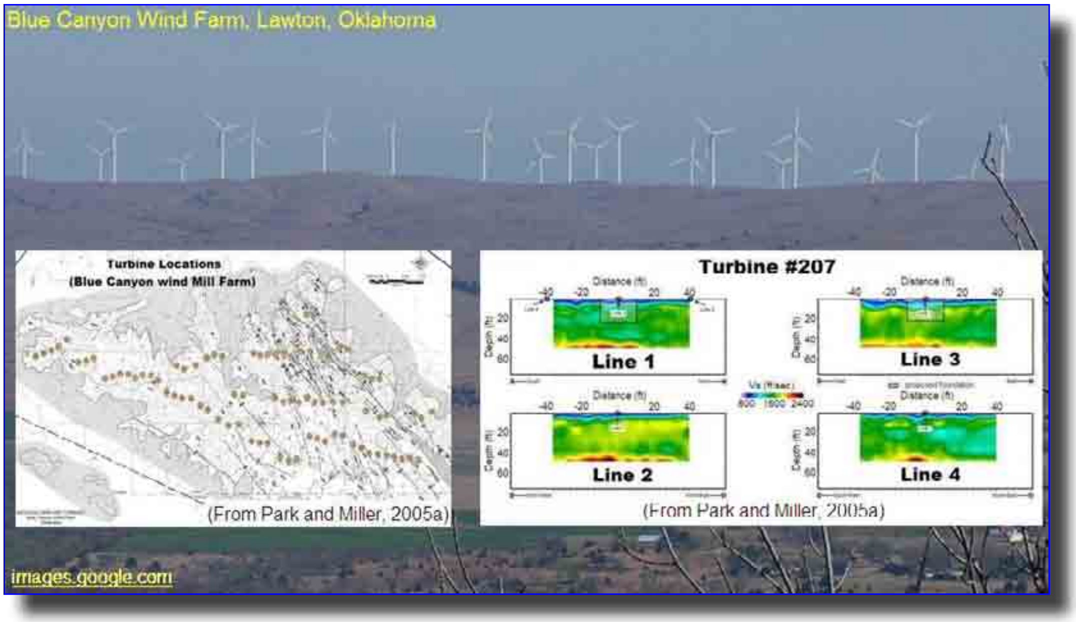


Figure 2. Blue Canyon Wind Farm near Lawton, Oklahoma, a turbine location map, and an example of multiple 2-D shear-velocity (Vs) profiling at one turbine site (from Park and Miller, 2005a).

experience continuous vibration caused by the rotating blades. Because of the vibration, the dynamic properties of ground materials provided from a seismic survey can be especially pertinent from geotechnical engineering perspectives. Further, considering the extent of ground materials influencing the safety and sustainability of the tower being much more extensive than the direct area occupied by the tower, the conventional approach of drilling one or more places at the tower center may not be sufficient to ensure overall safety and stability. Because a few instances of fatal crane failure caused by collapsed ground during the tower construction have been reported, it seems this safety zone may need to be expanded even further (Figure 3).

Figure 3. Turbine tower foundation construction (left) and tower-lifting crane (right).

The seismic investigation usually deals with the bulk-property evaluation of the ground, with the bulkiness increasing with depth. A continuous survey is usually performed to generate a 2-D (and 3-D) cross-section image of the property, usually in stiffness as depicted by shear-wave velocity (Vs) information (Figure 4). Shear-wave velocity (Vs) is often used as a direct indicator of the shear (and sometimes Young's) modulus. The seismic survey can be a more thorough and appropriate approach for site characterization than conventional drilling (Figure 4). Because a seismic survey does not need the bulky, heavy equipment that drilling does, the convenient accessibility to the site is another advantage. Often this survey can take place without construction of access roads. Overall cost is also usually some fraction of the drilling cost.

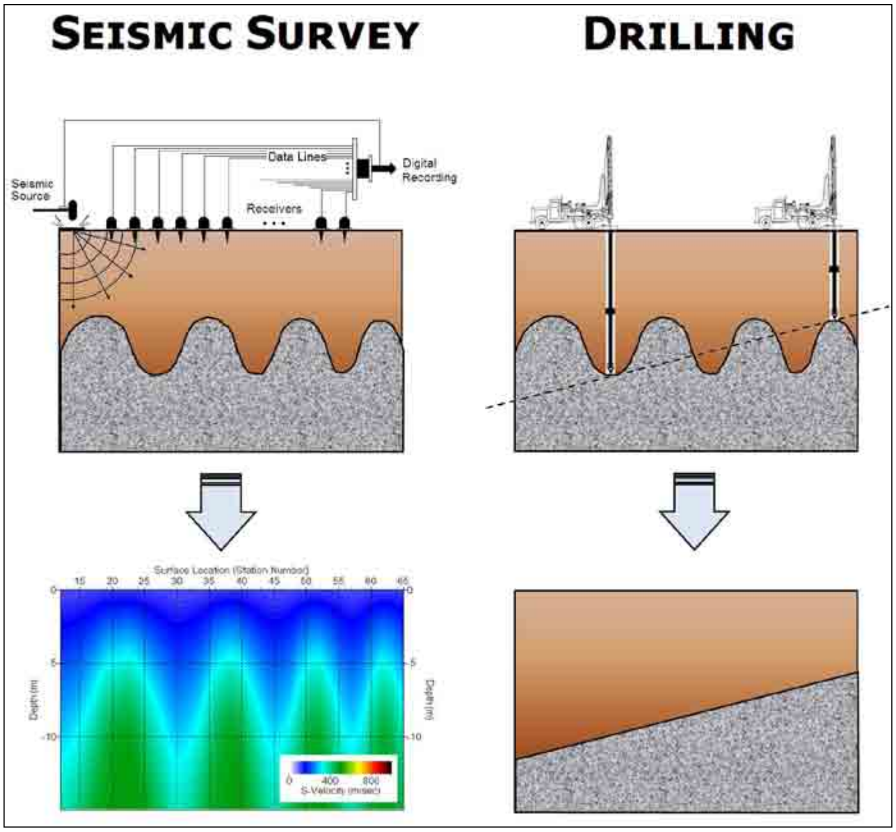


Figure 4. Advantage of seismic surveys in comparison to conventional drilling.

Approaches Taken in Wind-Turbine Site Characterization

Several different approaches are taken either independently or in combination in wind-turbine site characterization. They include shear-wave velocity (Vs) profiling (1-D, 2-D, and 3-D), side-scattering analysis (SSA), and subsidiary results from the Vs profiling — including average and interval velocities and a bedrock topography map. Then, a comprehensive analysis to detect voids and anomalies is usually taken as the final approach.

Shear-Velocity (Vs) Profiling

Various types of surveys can be taken depending on the thoroughness of the site characterization being sought. If only the overall vertical (depth) variation of stiffness information is needed, then 1-D Vs profiling is sufficient (Figure 5). If the lateral variation information is also important, 2-D profiling can be conducted in a specific direction (Figure 5). Considering that the minimum field operational cost for 1-D profiling is usually comparable to the cost for 2-D profiling, a 2-D profile is usually the recommended minimum approach. An anomaly — defined as a localized area

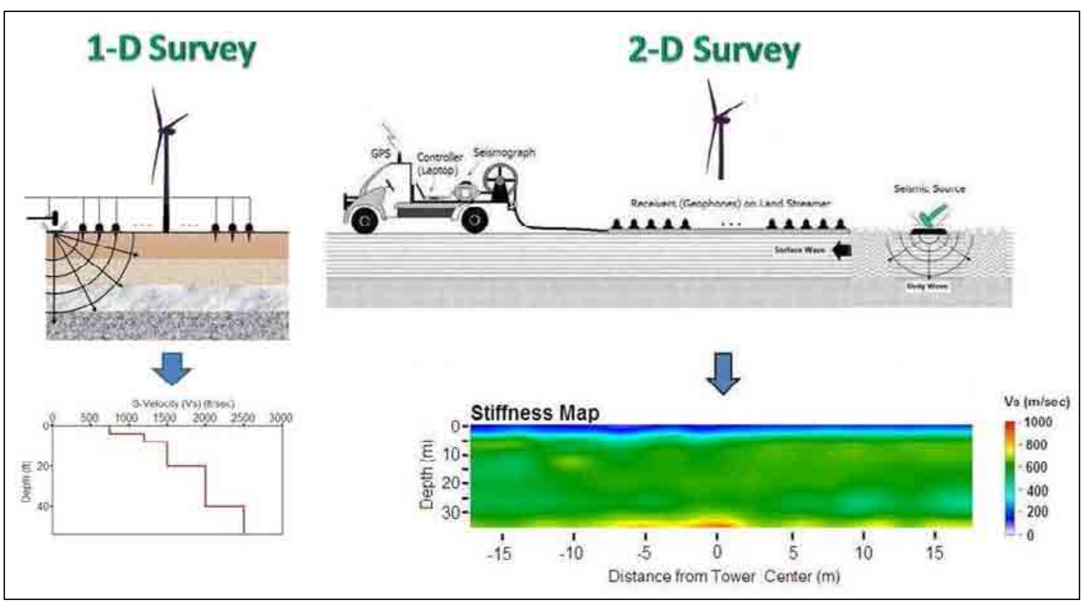


Figure 5. 1-D and 2-D wind-turbine site characterizations by the MASW method.

significantly different in elastic property (strength and density) than ambient material — can be delineated through either 1-D or 2-D profiling if its size (dimension) is significant (for example, greater than 20 percent of its depth).

In practice, an approach of multiple (for example, four) 2-D profiling in different directions at different places within the same site has been usually taken to maximize the thoroughness of the characterization for a given deployment of field equipment and crews (Figure 2). This approach makes it possible to evaluate the stiffness information at a regional, as well as local, scale. Average and interval shear velocities are also provided as by-products from each 2-D profiling (Figure 6). A pseudo 3-D map of bedrock topography is constructed at this stage, based on the arbitrary high value of Vs immediately following the top soil layer mapped (Figure 7). In addition, this multiple 2-D profiling approach enables detection of shallow voids and cavities (depth 10 m or less) — the most dangerous potential hazards — through a special processing approach called side-scattering analysis (SSA).

Side-Scattering Analysis (SSA)

Surface waves are known to be sensitive to the presence of near-surface anomalies such as near-vertical fractures and voids. A significant amount of surface-wave energy impinging against them is transformed into scattered surface waves due to anomalies acting as new sources of surface waves (Figure 8). Therefore, MASW data collected for normal 2-D Vs

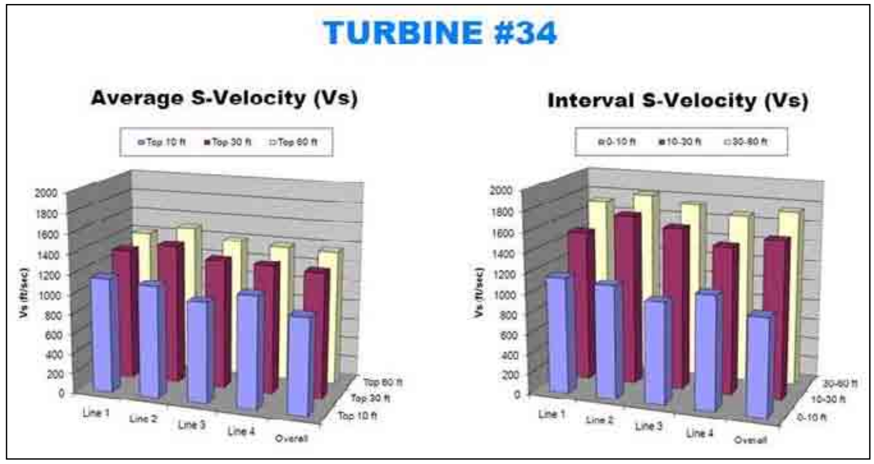


Figure 6. Display of average and interval shear-wave velocities for four (4) lines surveyed at a proposed turbine site in a Midwest state.

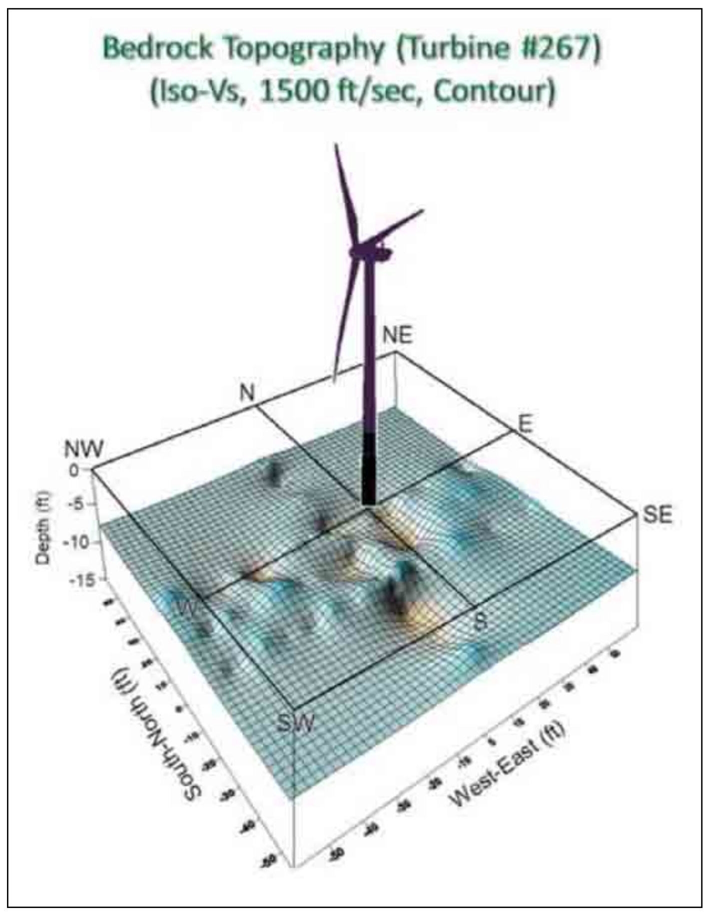


Figure 7. Bedrock topographic map constructed from iso-velocity contouring from four (4) lines of 2-D Vs data at a proposed turbine site in a Midwest state.

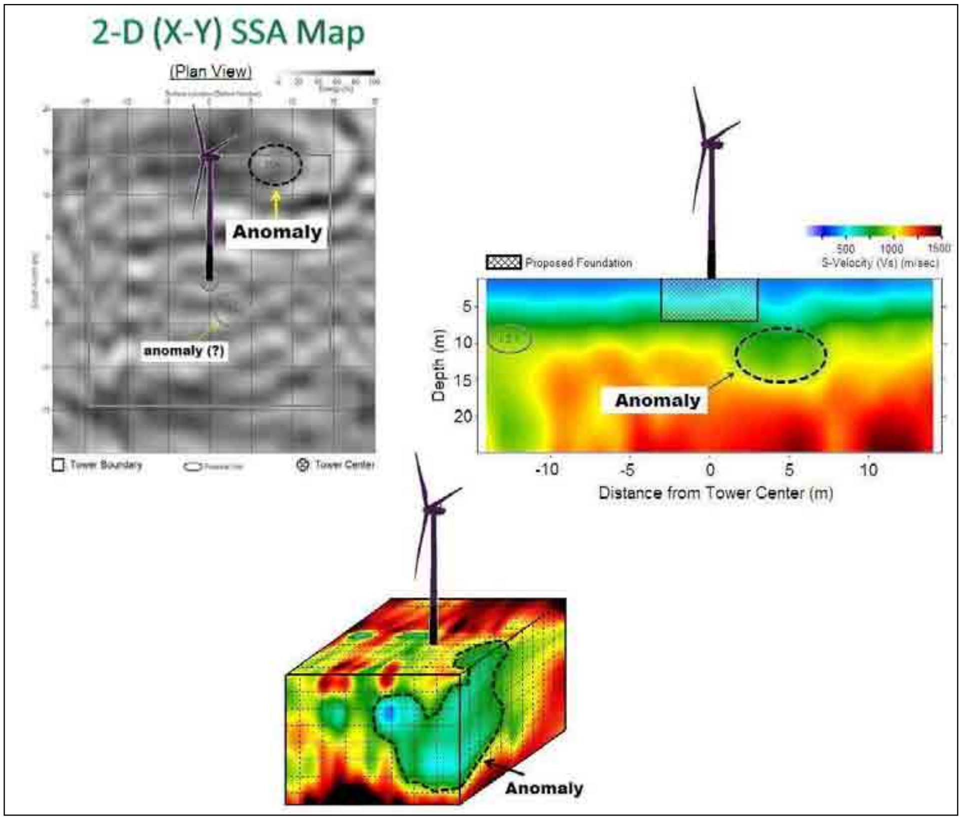


Figure 8. Side-scattering-analysis (SSA) map (upper left), 2-D Vs map (upper right), and 3-D Vs map showing a potential anomaly at a proposed turbine site in a Midwest state.

mapping can be used to detect possible subsurface anomalies existing off the survey line by using a processing scheme similar to conventional reflection processing. This process is called side-scattering analysis (SSA) of surface waves. Its effectiveness increases with the number of survey lines occupying different locations at a given site. With this approach, focal depths can be controlled by changing the frequency (wavelength) range used for the processing. A brief explanation of the processing scheme can be found in Park and Miller (2005a; 2005b).

3-D Approach

Recently, 3-D processing has been applied to generate a cubic grid Vs data set by using multiple sets of 2-D Vs data. Close spacing of multiple 2-D Vs maps makes it possible to use them for the construction of a 3-D (cubic) data set through a proper 3-D interpolation scheme (Figure 9). Considering that only plane-wave components are selectively processed during the dispersion imaging process for a 2-D profile, and all other offline waves such as side scatterings are exclusively suppressed, this independent use of each 2-D profile for the 3-D spatial interpolation can minimize adverse effects from the sideswipe energy, producing 3-D data in the simplest manner (Park and Carnevale, 2009). Display of 2-D slices extracted from this cubic data set along three orthogonal axes (x, y, and z) can be a highly effective tool to understand the 3-D elastic characteristics of the site (Figure 9).

Void (Anomaly) Detection

Although a large-size anomaly can be detected from the (1-D and 2-D) Vs profiling previously outlined, a more effective detection of such a significant anomaly as a void can be accomplished with the side scattering analysis (SSA) previously described. The most comprehensive approach, however, is the combination of and cross checking between different types of data with the highest priority on the SSA results. For example, if a suspicious scattering feature is identified from an SSA map, then existence of the velocity anomaly is examined on the 2-D (or 3-D) Vs maps previously obtained for those portions near the locations identified on the SSA map (Figure 8). If a location is close to a 2-D survey line, then the existence of the back-scattering feature is also examined on the adjacent field records (Figure 10).

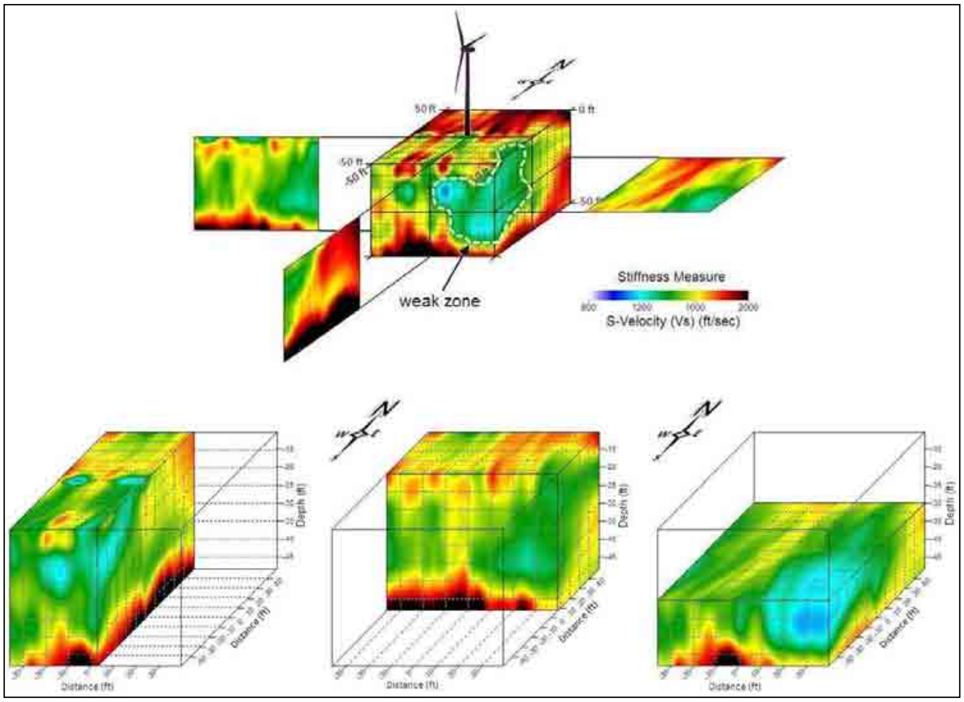


Figure 9. 3-D shear-velocity (Vs) mapping of a proposed wind-turbine site in a Midwest state displayed in cubic and layer-slice modes (top) and layer-stripping modes along three orthogonal x-y-z axes (bottom).

Combining all these types of information, a confidence level (usually in a scale from 1 to 10, with 10 the highest level) is assigned to the identified anomaly (Table 1). Field engineers use this information in conjunction with other types of information — local geology, results from other types of surveys (for example, a ground-penetrating-radar survey), and drilling — to make the decision on the next approach to be taken.

Future Directions

Because some difficulties with MASW analysis over hard-rock surface (outcrop) areas were reported where there was a tendency to overestimate shear velocities (Hutchinson and others, 2008), the analysis approaches in both dispersion curve and inversion may need special care somewhat different from

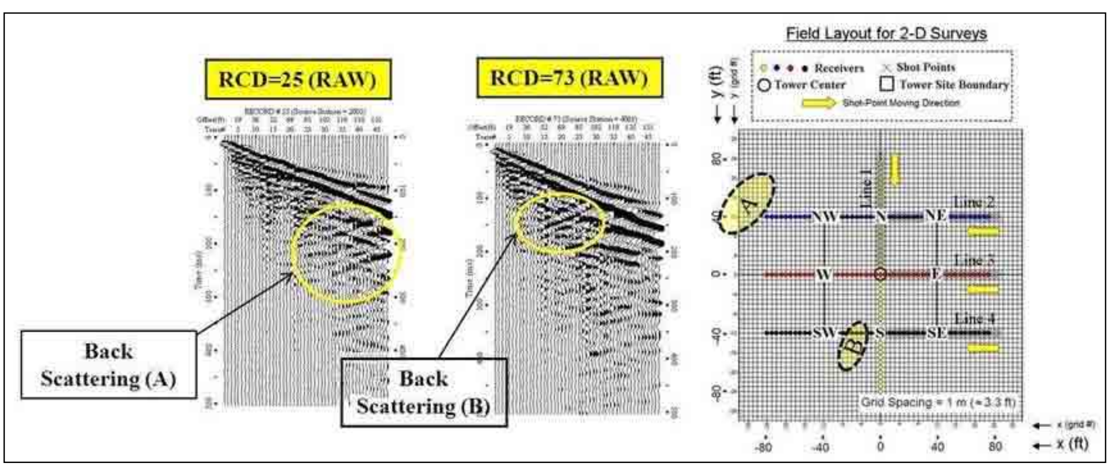
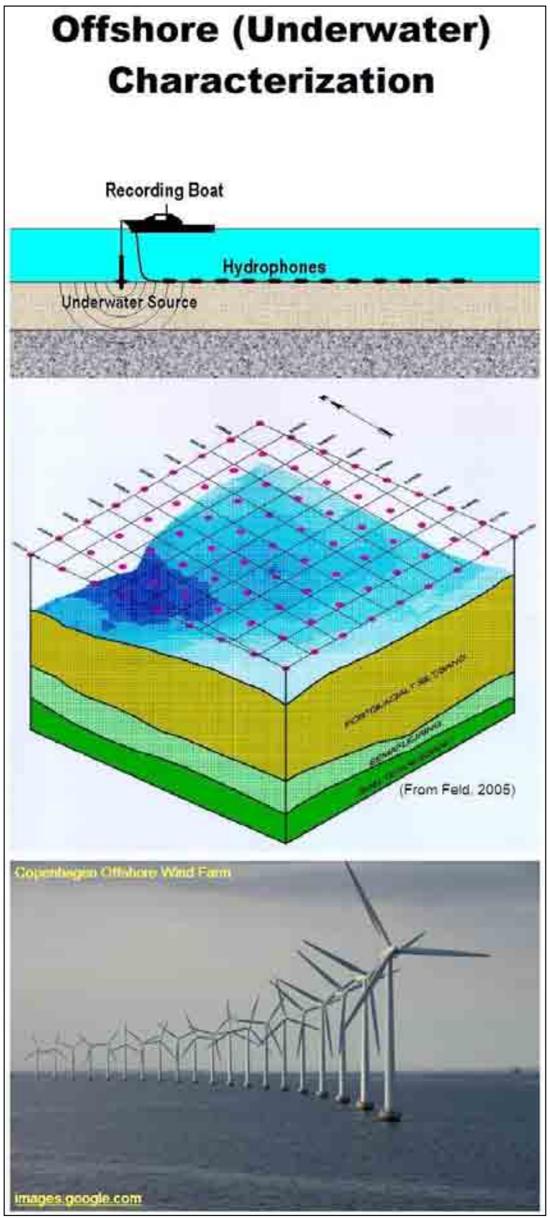


Figure 10. Anomalies (A and B) identified from the back-scattering features on field records and corresponding locations on the field map.

Table 1. Part of the summary table of potential anomalies at Blue Canyon Wind Farm-Phase II (from Park and Miller, 2005a).

Tower #	Label[1]	Location and Dimension of Potential Void[2]	Confidence Level[3]
201	L1-1	3.3 m North, 0.0-m East in 6.9-12.2 m depth and 2.3 m diameter	3
	SSA-1	2.9 m North 1.0 m East in 2.0-10.0 m depth and 3.1 m diameter	6
202	L1-1	0.9 m South, 0.0-m East in 4.9-8.9 m depth and 2.9 m diameter	6
	L1-2	5.8 m South, 0.0-m East in 5.6-9.4 m depth and 2.8 m diameter	6
	L2-1	14.6 m North 12.6 m West in 7.5-11.4 m depth and 2.8 m diameter	7

[1] Name marked on the reported maps of 2-D Vs, side scattering analysis (SSA), and surface-wave imaging by attenuation (SIA).
[2] Location from the center of the tower and maximum dimension possible
[3] Confidence level of interpretation: 0=No Confidence, 10=Absolute Confidence



that for the soil-site analysis. This will require additional and special care in field logistics to avoid possible dominance by higher modes and resonance energy. The 3-D approach may find significant utility when combined with proper data presentation tools for those geotechnical engineers who deal with load capacity and safety issue of the site characterization in both detailed and overall manners. This approach will need to develop more cost-effective field logistics yet maintain (or further improve) the overall effectiveness of 3-D characterization. This development can also consider the possibility of body-wave velocity (Vp) analysis through the refraction method for mapping Poisson's ratio (Ivanov and others, 2000).

Another potential application exists in offshore site characterization (Figure 11). Although deep-water application (greater than 100 m, for example) with indirect source and receiver coupling was previously attempted (Park and others, 2005), it is highly recommended to use direct coupling for the most optimal data collection (Figure 11). This underwater application can be highly efficient as a reconnaissance tool for a regional — as well as local in the case of individual turbine sites — mapping of an offshore area.

Relatively small voids at depths influencing the safety during and after construction can be more effectively mapped by ground-penetrating radar (GPR). Considering even a few inches of abrupt collapse at the crane pads during the tower-

Figure 11. Conceptual diagram showing underwater MASW survey with direct-coupling source and receivers (top), possible 3-D characterization from a reconnaissance survey of a proposed offshore wind farm (middle) (Feld, 2005), and an existing farm offshore at Copenhagen, Denmark (bottom).

building stage can lead to catastrophe, a detailed very-shallow (less than 2 m) GPR survey at potential crane locations around the turbine-tower position may play a critical role.

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Evaluating GPR for Geotechnical and Hazards Assessment of Deep-Mine Geology

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Introduction

Geotechnical issues associated with the longwall mining technique in American coal mines is an ongoing area of concern for coal mine engineers and mine safety oversight groups. The longwall method involves the mechanical shearing of coal from a subsurface seam along a face with a horizontal extension of 300 meters or more. Extracted coal falls onto a conveyor belt system that removes the coal from the work area. As the longwall shearers, protected by hydraulic roof supports, advance into the coal seam, overlying rock that is no longer supported is allowed to collapse behind the operation (www.wikipedia.org/wiki/coal_mine). The manner in which the collapse occurs may depend in part on the nature of the overlying rock strata, such as the lithology, presence of bedding planes, fractures, faults, and pore fluids. The ability to geophysically image these geologic features could provide for improved parameterization of geomechanical models aimed at better understanding and designing for both controlled collapse and avoidance of rock ruptures – the latter commonly referred to as mine bumps.

Multiple geophysical techniques have been employed and described in the scientific and engineering literature for imaging near-surface geology. Applications of surface techniques are largely irrelevant in the environment of many active longwall coal mines due to the depth of operations (greater than 300 m). *In situ* (underground) geophysical operations may be seriously hampered by site conditions, safety concerns, and seismic and electromagnetic noise.

Figure 1. Custom-designed hoist apparatus for GSSI's 100- and 200-MHz antennas. The hoist, with elevation control, is mounted in the bed of a pickup for continuous radar profiling of the mine ceiling.

A proof-of-concept geophysical survey employing ground-penetrating radar (GPR) to image sedimentary rock strata immediately above and below a mined coal seam at an active longwall mine in Carbon County, Utah, was commissioned by the Prevention of Catastrophic Events Branch of the National Institute for Occupational Safety and Health (NIOSH). GPR is most commonly applied to the imaging of geologic structure as a surface technique. Numerous examples can be found in the scientific and engineering literature of such applications for imaging near-surface coal seams and structural issues related to historic coal mine activity. The application of GPR to *in situ*, underground issues within active coal mines is both novel and experimental (Jha and others, 2004; NIOSH, 1997; Ralston, 2007; Strange and others, 2005). In this particular application, the concept to be evaluated involved not so much that GPR could image geology adjacent to the mine passages, but the manner in which GPR data could be operationally collected (upwards, downwards, and laterally) in a wet, dark, and electromagnetically "noisy" environment.

Instruments

The instrumentation utilized in this study was a GSSI, Inc. SIR-3000 GPR system with 400-, 200-, and 100-MHz antennas. It was anticipated that the 200-MHz antenna would provide depth penetrations of up to 5 m in ideal conditions, with the 100- (monostatic mode) and 400-MHz antennas providing penetrations of up to 14 m and 2 m respectively. Space and portage limitations in the mine environment precluded the use of the bistatic configuration, a configuration that potentially provides depth penetration as great as 27 m.

GSSI's 400-MHz antenna is designed to be cart-mounted for easy and rapid surveying over level, unobstructed ground. The larger dimensions of the 200- and 100-MHz antennas necessitated a towing apparatus whereby the antenna sits on a plastic sled that is flush to the ground surface. This would be the setup appropriate for imaging the mine passage floors. Imaging upward into the mine passage ceilings required a special hoist cart to be mounted in the bed of a pickup, with the antennas supported upside down. This apparatus was designed and built by NIOSH personnel for this project (Figure 1).

Survey Site

The candidate mine for this proof-of-concept study is located in a region of the Wasatch Plateau, Utah, currently home to the deepest coal mining operations in the country. The primary seam is a 2- to 3-m-thick layer of high grade bituminous coal of upper Cretaceous age in sandstone and siltstone sequences of the Blackhawk Formation. The coal seam can be seen in outcrop along the face of the Book Cliffs whereupon it descends into the subsurface at a 12 to 14° angle. Mining operations commenced in the late 1990's at the outcrop itself and present longwall operations are now operating at depths greater than 600 m. Access to the current longwall is by drivable passage several kilometers long. Multiple locations were selected in access passages along strike of the coal seam for evaluation of the GPR system and associated hoist. Mine passage floors were generally wet or damp, with puddles in low spots and along the downdip side of the passage. Ceilings were generally dry and were structurally supported in all locations with 10 cm (4 inch) open wire (6 gauge) mesh attached to the ceiling with 2-m-long bolts and plates on 1.2-m centers.

It was anticipated that the wire mesh and bolt hardware supporting the ceilings throughout the access passages of the mine would pose significant problems to the use of GPR for imaging upwards into the overlying strata. Metal is highly reflective of microwave energy – a fact not lost on one of the most common uses of GPR, that of imaging rebar in concrete slabs. While a continuous sheet of metal would certainly act as a perfect reflector (transmitting nothing), the response of a wire mesh (at the anticipated antenna frequency) was uncertain.

Prior to the commencement of the Utah project, a field experiment was conducted to test for the effects of an identical wire mesh (as used in the mine) for blocking or attenuating the GPR signal. At a field site, a 6-gauge, 10-cm wire mesh in a 1.5 x 1.5 m sheet was placed on the ground surface at the centerpoint

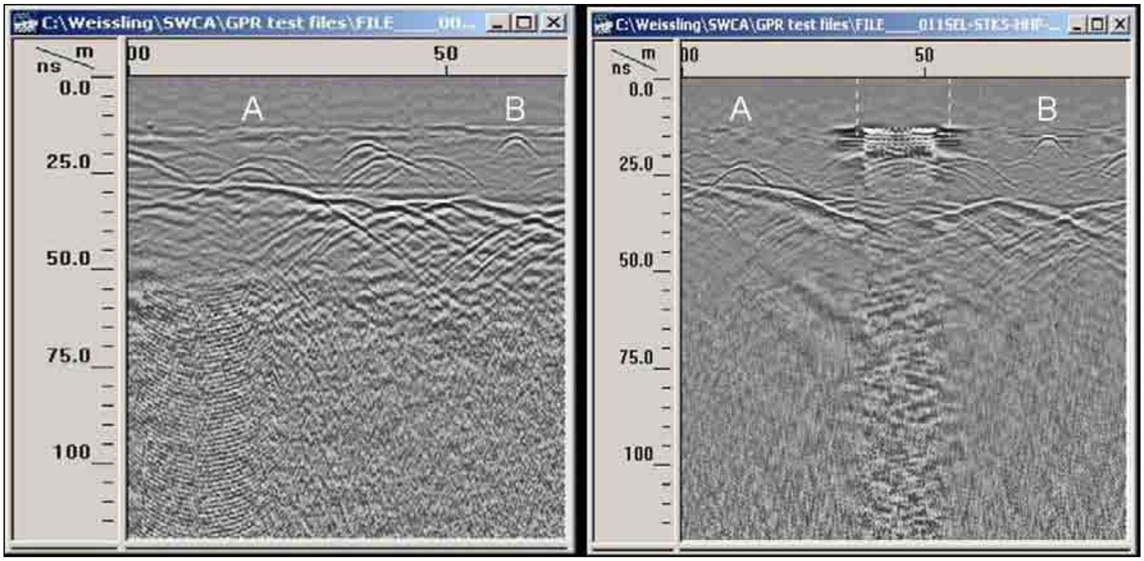

Figure 2. Radargrams (200 MHz) of an evaluation of microwave attenuation/transmission effects of a wire mesh at the antenna-ground coupling position. For positional reference, features A and B (diffraction hyperbolas) are identified in both panels. The dashed vertical lines in the right panel represent the location of the wire mesh sheet.

of a 9-m-long GPR transect. A 200-MHz antenna was towed along the transect before and after placement of the metal mesh. Figure 2 shows the GPR radargrams of the before and after transects.

Both radargrams were post-processed to remove antenna ringing using FIR filtering and deconvolution. In both panels the ground surface is seen as the horizontal reflector at approximately 12.5 nanoseconds (ns). The stronger reflector between 25 to 35 ns likely represents an eroded bedrock (sandstone) horizon. As can be clearly seen, the wire mesh significantly degraded and attenuated the underlying radar returns. Despite a strong noise component propagating through the entire radargram, it appears that some true reflection signal persists – a somewhat encouraging result for the GPR acquisition in the mine.

To facilitate the calculation of the approximate dielectric permittivity of the regional sedimentary strata as well as the determination of the potential depth range

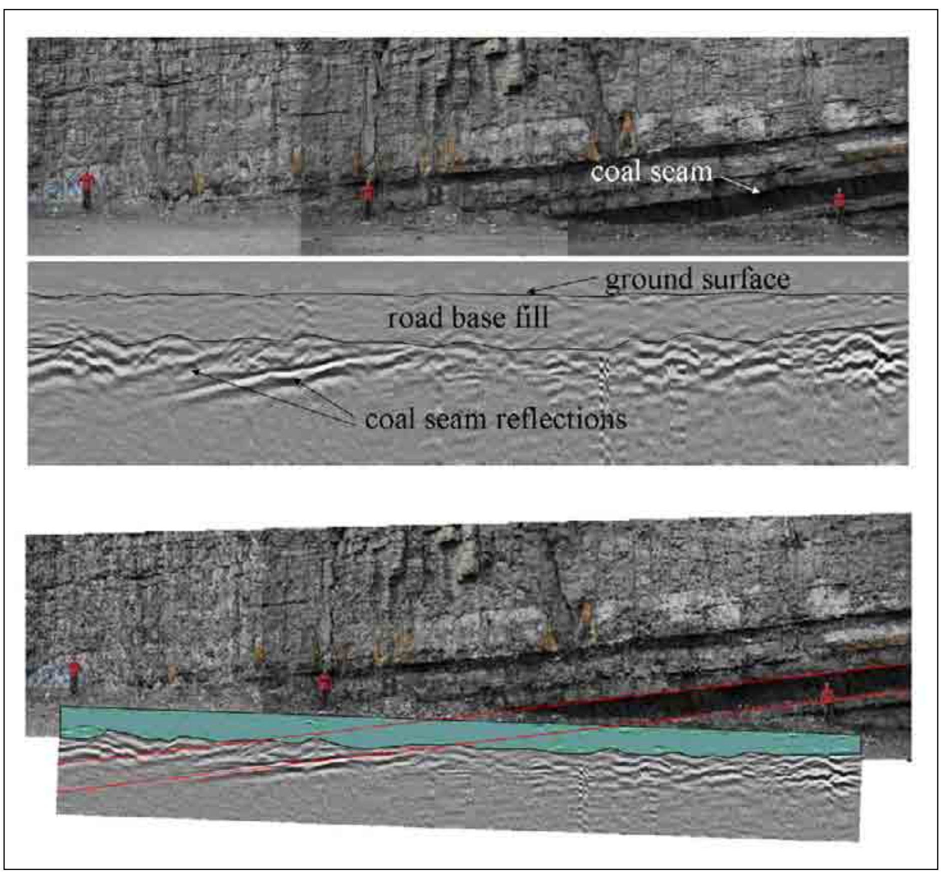

Figure 3. Photo-collage of road cut coal seam and sandstone strata (top panel) with GPR 200-MHz radargram of subsurface (middle panel). Lower panel depicts registration of photo (stretched to correct perspective) and radargram (compressed vertically to match coal seam inclination). Green layer in radargram depicts road base fill material.

of the 200-MHz antenna, a calibration experiment was conducted with the 200-MHz antenna at a site outside of the mine – a site consisting of a sandstone/coal seam strata sequence where the depth to the coal seam could be determined. A site was identified at a nearby highway roadcut with a dipping 1-m-thick coal seam in a sandstone sequence. A 30-m transect was centered at the point at which the coal seam intersected the ground surface at the base of the roadcut wall. The resultant 200-MHz radargram was post-processed to remove the standard background antenna ringing noise, and then spatially transformed (rotated and stretched) for subsequent registration with a photographic collage of the roadcut wall (Figure 3).

As can be seen in the figure, there is a very good match of the dipping reflectors in the radargram with the top and bottom edges of the coal seam seen in the roadcut. The observation that the reflectors do not extend to the actual surface is consistent with a layer of intervening road base fill material. The calculated dielectric permittivity of the fill material was 16, a value consistent with unconsolidated, packed fill, while the calculated dielectric of the coal and adjacent sandstone was 6.5.

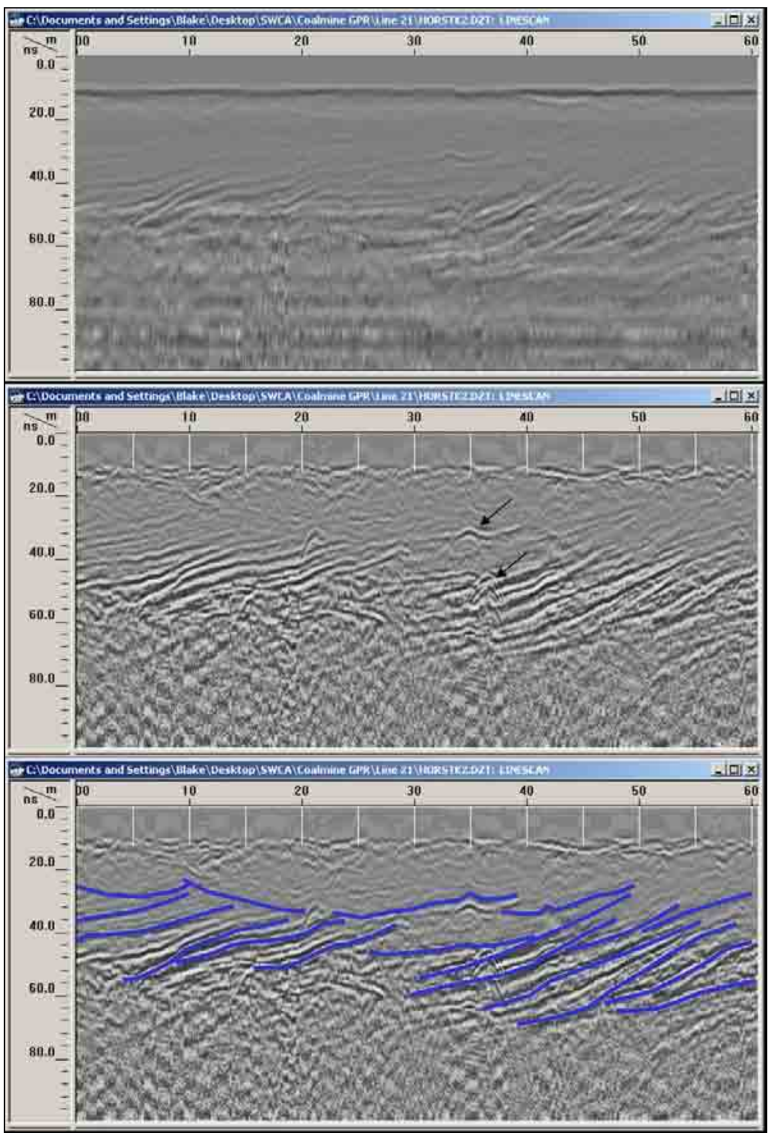

Figure 4. Raw (top panel), post-processed (middle panel), and interpreted (lower panel) radargram (200 MHz) of a 55-m profile of the passage floor. Radar reflections are consistent with sandstone cross-bedding structure. Arrows denote a structural hump and possible disturbance area (diffraction hyperbola).

Results

The on-site evaluation of the three antennas, consisting of level transects along roads across the surface outcrop of the coal seam, suggested the best results would likely be obtained with the 200-MHz antenna. The primary survey activities commenced with the acquisition of several continuous-motion 200-MHz transects in two discrete mine locations, of both floor and ceiling.

On-site evaluation of the raw radargram from a 55 m floor transect revealed relatively clean radar reflections suggesting cross-bedding in the underlying sandstone member. Post-processing of the raw radargram (horizontal banding removal, deconvolution, and band-pass filtering) significantly improved image quality (Figure 4). This floor profile was re-shot in reverse direction to confirm the cross-bedding interpretation.

Of particular interest along this transect is the anomalous structure and diffraction hyperbolas (denoted by the arrows on the middle panel). An inspection of the passage floor, in the area immediately above these radar anomalies, revealed a subtle topographic hump eliciting a hollow sound when tapped with a hammer. This hump and associated sound was interpreted as emanating from a structural buckling and possible bedding plane separation of the floor strata – both precursors to potential rock ruptures.

Two attempts were made at acquiring continuous profiles of an approximately 60-m span of the ceiling using the 200-MHz antenna. For the first profile, the antenna was mounted on the hoist apparatus and was raised to a position that would maintain a maximum 45 cm offset from the ceiling. Actual standoff ranged from 10 to 45 cm along the profile due to undulations in both the ceiling and floor. The resultant raw radargram was essentially overwhelmed by ringing echos between the antenna, wire mesh, and ceiling surface (top panel, Figure 5). Post-processing removed the majority of the ringing echos as can be seen in the bottom panel of Figure 5, yet a strong noise component remained. We interpret this noise structure as arising from the bolts and bolt heads, essentially a series of strong point diffractions. A count of the number of vertical noise trains in this radargram, approximately 50, is consistent with the number of bolt heads encountered along this 60-m transect (at 1.2 m centers). The quiet zone in the radargram at position 300 represents a pause in the data collection (driver stopped vehicle).

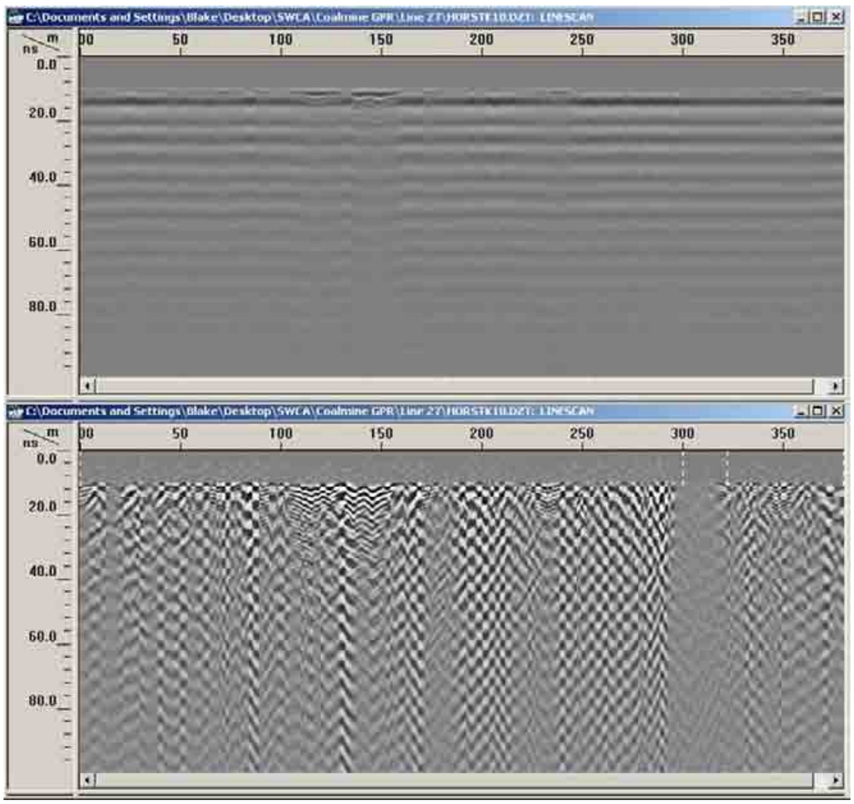

Figure 5. Raw and processed radargrams (200 MHz) of a 60-m ceiling profile. Antenna offset from the ceiling (wire mesh) ranged from 2.5 to 45 cm. Upon removal of ringing echos, processed radargram reveals underlying noise structure from metal ceiling bolts and bolt heads.

Conclusion

The NIOSH/Utah Mine GPR project was a qualified success with the primary objective being a proof-of-concept of the GPR technology for a specific geophysical application. Conceptually and operationally, GPR probably represents the most applicable *in situ* geophysical technique for assessing geologic structure and strata surrounding a coal seam mining operation, given the environmental and logistical constraints. As was demonstrated by both the pre-survey field trial and work at the mine site, the metal roof-support system was incompatible with the GPR technique. Future work will continue to assess GPR techniques for imaging sub-floor geology, especially in regards to identifying anomalous faulting and structural buckling of strata.

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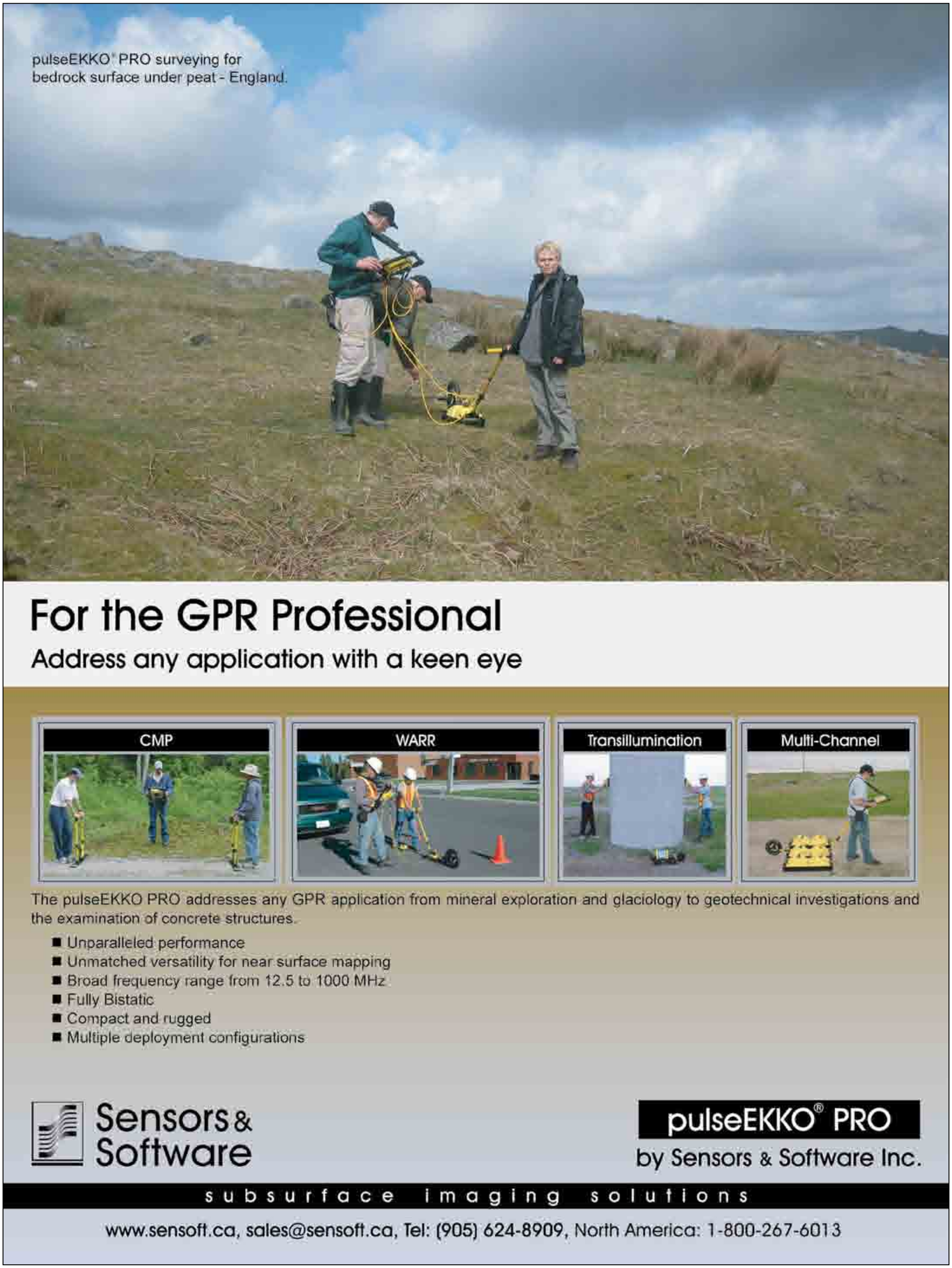
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Applications of Geophysics in Geotechnical Investigations and Mitigations of Distressed Flood Control Dams in an Arid Environment

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Introduction

Conditions assessments and safety updates of existing earthen embankment flood control dams and flood retention structures (FRS) in arid regions present special challenges to geotechnical engineers. These structures can be miles in length, and although designed to retain floodwaters during rare, large storms, they remain dry except during and after those rare events. Cracking may present the opportunity for piping erosion to lead to dam failure, but identifying and locating such cracking, if it is a hazard, is a daunting task. Over-pumping of groundwater in alluvial basins for agricultural, municipal, or industrial use can result in the particular hazard of land subsidence and, in specific areas, earth fissures due to ground tension from differential land subsidence. An earth fissure is a ground crack with a typical aperture from a fraction of a centimeter to an several cm or more and traceable, connected length of potentially thousands of meters. If it passes under an earthen flood control structure, an earth fissure can provide a connected pathway for concentrated piping erosion and failure of the structure. Even without earth fissuring, land subsidence can change flood control structure crest elevations and hydraulic behavior.

Land subsidence and earth fissuring is a problem or concern in several areas of central Arizona, and impacts several flood control structures in areas of rapidly expanding suburban development. The Flood Control District of Maricopa County (FCDMC) in Arizona has a mission and commitment to continued excellence in reducing flood risks for the people of Maricopa County, Arizona by providing comprehensive flood and storm water management services. As part of its mission, the District operates and maintains 22 flood control dams, which provide highly beneficial flood protection for significant portions of Maricopa County. The District's comprehensive Dam Safety Program includes: recurrent dam safety activities, ongoing assessments of the dams, and a rehabilitation program for many of the dams to assure flood protection is sustained well into the future. Engineering geophysics is an important set of geotechnical tools in this assessment and rehabilitation program. Geophysical methods being applied in this program include shallow refraction seismic and Refraction Microtremor™ seismic, surface resistivity, gravity, and, when available, historic borehole geophysical data. Efficient deployment of surface geophysical methods and data collection is frequently optimized using satellite-based interferometry by synthetic aperture radar (InSAR) to provide recent (1992 to present) geographic subsidence information.

Relevant Geological and Geophysical Conditions

Shallow geologic characterization for foundation conditions, including presence or absence of earth fissures, needs to be addressed. The very shallow geologic profile usually consists of slightly moist to dry mixtures of sand, gravel, silt, and clay (Holocene) soils overlying a cemented (Pleistocene) soil horizon beginning at typical depths of 0.6 to 1.5 m. As described in Rucker and Fergason (2006), cementation can range from weak to rock-like, and can vary widely over short lateral distances. Horizon thickness may range from 1 to 10 or more m. Occasional uncemented sand-gravel buried streambeds (paleochannels) may be incised in this horizon; spacing between these channels may be on the order of 100 to more than 300 m. A less cemented to sometimes uncemented horizon typically underlies the cemented horizon. A water table is rarely present in the shallow subsurface, and the soils are normally slightly moist to nearly dry. The soil characteristics are typically unsuitable for GPR (McGill and Sternberg, 1995), and correlation of electrical properties to geotechnical engineering characteristics in these mixed finer- and coarser-grained soils tend to be inconclusive. Shallow seismic refraction provides means to profile the top of the cemented horizon and quantify cementation strength as described by Rucker and Fergason (2006). Standard arrays of 10-ft (3-m) spacing using 12- to 24-geophones with sledgehammer energy sources every 10 ft (9.1 m) provide an effective compromise on field data collection and interpretation detail. Furthermore, earth fissures and other significant discontinuities can be detected and located using these arrays as described by Rucker and Keaton (1998) and Rucker and Holmquist (2006). Refraction Microtremor™ (Louie, 2001) surface-wave measurements are also obtained using these same array setups to characterize the underlying less-cemented horizon (and deeper horizons) despite the common presence of a seismic-velocity reversal. Rucker (2006) details geotechnical applications of combined seismic refraction and surface wave interpretations.

To address land subsidence potential, aspects of the deep alluvial basin geometry and geology need to be understood. Groundwater tables in these basins are commonly at depths of 100 m or more, and in many areas have declined by 30 to as much as 100 m or more due to overpumping. Such declines have caused large increases in effective stresses imposed on the alluvial basin materials. Resulting compaction of the basin materials has been manifested as subsidence at the surface. Subsidence magnitude is ultimately a function of the various basin materials compressibility (moduli) and thickness. Although gravity surveys are a standard tool to estimate basin depths to bedrock, useful interpretations need some form of calibration to known depths and lithologies to reduce multiple uncertainties, especially density assumptions. Deep well geophysics, especially resistivity logs to depths greater than 300 m, can provide immensely detailed data at a specific point. Such information collection is usually cost prohibitive and when available, is historic or legacy data. When deep drilling data is missing, inexpensive, simple surface geophysics can provide some useful information for basin material geometry and geology. Using Refraction Microtremor™ with long geophone arrays, shear (s)-wave velocity profiles can provide interpreted bedrock depths on basin fringes to greater than about 100 m. These s-wave interpretations then “calibrate” density assumptions for gravity depth to bedrock interpretations at the basin fringes before projecting the interpretations (especially densities) to greater depths. Resistivity appears to be a qualitative indicator of basin material subsidence behavior. Where terrain and a lack of cultural interference permits, deep resistivity soundings can be as simple as Wenner 4-point arrays with large pin spacings ranging up to a maximum of 300 m. Basin material zones with very low resistivity (commonly less than about 10 ohm-m) tend to behave as massive clays with large compressibility (significant subsidence) but very low permeability. Groundwater drains from such zones very slowly, so that subsidence has long time delays. Basin material zones with intermediate resistivity (commonly about 10 to 30 ohm-m) tend to have moderate compressibility and permeability. Groundwater drains from such zones fairly quickly, so that subsidence response to groundwater table decline is rapid. Finally, basin material zones with higher resistivity tend to have low compressibility, and tend to have little contribution to land subsidence. Typically, deep (commonly greater than about 300 m) highly resistive zones behave as essentially incompressible bedrock even though their density is lower than true bedrock.

Example Project: McMicken Dam

McMicken Dam is a 14-km long flood control dam west of Phoenix, Arizona (Figure 1) that was constructed in 1955 to protect Luke Air Force Base and agricultural lands from rare floods. Over time, it has suffered distress due to differential land subsidence ranging from zero to more than 1.5 m caused by regional groundwater pumping. In 1981, earth fissures were discovered in the vicinity of, but not at, the southern end of the dam. These fissures were evaluated using available methods at the time, including low sun angle aerial photography (Beckwith and others, 1991) and exploratory trenches. As part of continuing conditions assessment, it was observed in 2002 that earth fissuring in the area was continuing, and that visible surficial features were trending towards the dam. Ground reconnaissance and an initial series of three test trenches, with depths as great as 3 m, revealed a significant fissure in two trenches but not in the third trench closest to the dam.

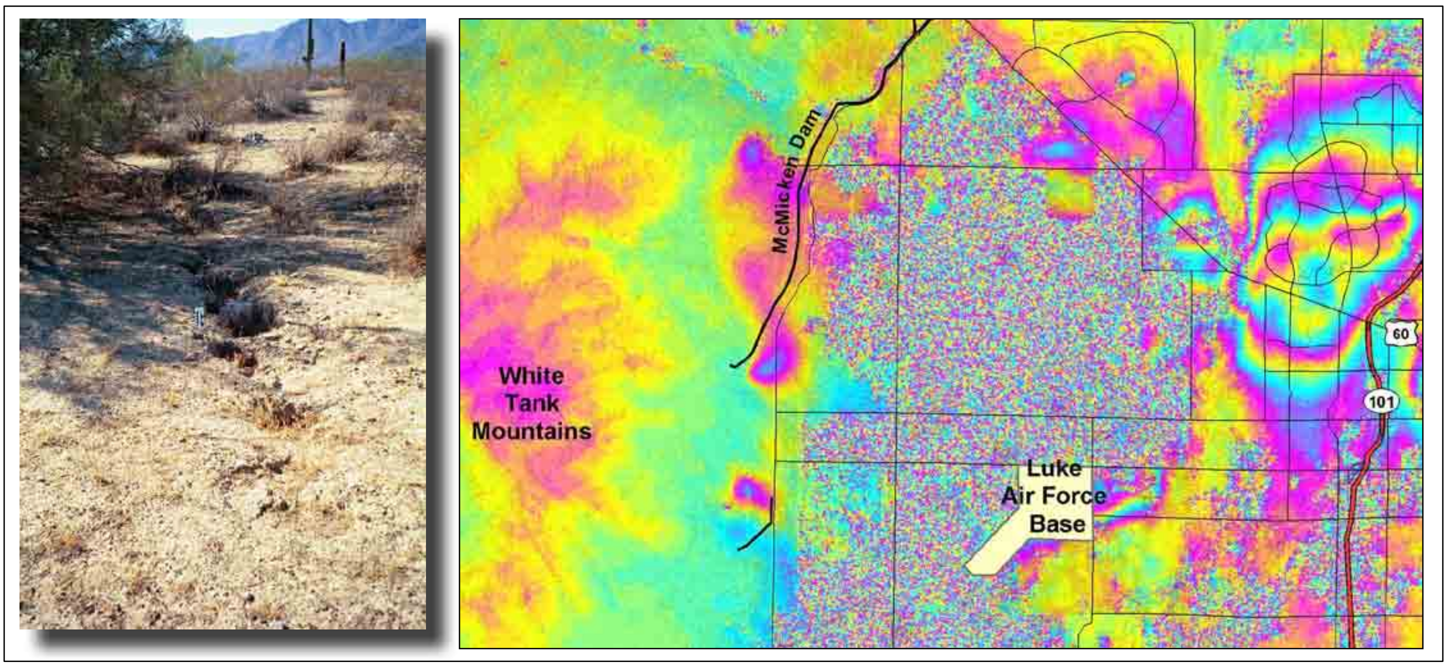

Figure 1. An earth fissure with surface expression of piping erosion (left), and a 32-km-wide InSAR image (ADWR, 2003) depicting relative land subsidence in the western Salt River Valley west of Phoenix, Arizona from December 1996 to 1999. Differential elevation change is presented as color change; a complete color cycle, such as blue to blue or yellow to yellow, represents 3 cm elevation change over the 3 years. General subsidence is apparent in Sun City, Arizona in the northeast corner of the image, and immediately east of Luke Air Force Base. Distinct subsidence bowls are apparent at the south end of McMicken Dam and at White Tanks No. 3 FRS about 3 km to the south.

Finding Earth Fissures

Rather than excavating large trenches blindly to try to find fissures, a seismic refraction method developed by Rucker and Keaton (1998), based on a concept explored by Wrege and others (1985), was used to try to locate seismic discontinuities that could be fissures. Multiple seismic discontinuities were identified using the seismic refraction method. Further test trenching at selected seismic anomalies confirmed the presence of earth fissures, some of which approached and trended under the dam (Figure 2). Aspects of the ensuing investigations, analyses, and mitigation of the dam in the fissure area are presented in Rucker and Fergason (2004) and Rucker and others (2008). Seismic refraction field work was completed in phases. First, technique verification and continuous exploration in the vicinity of identi-

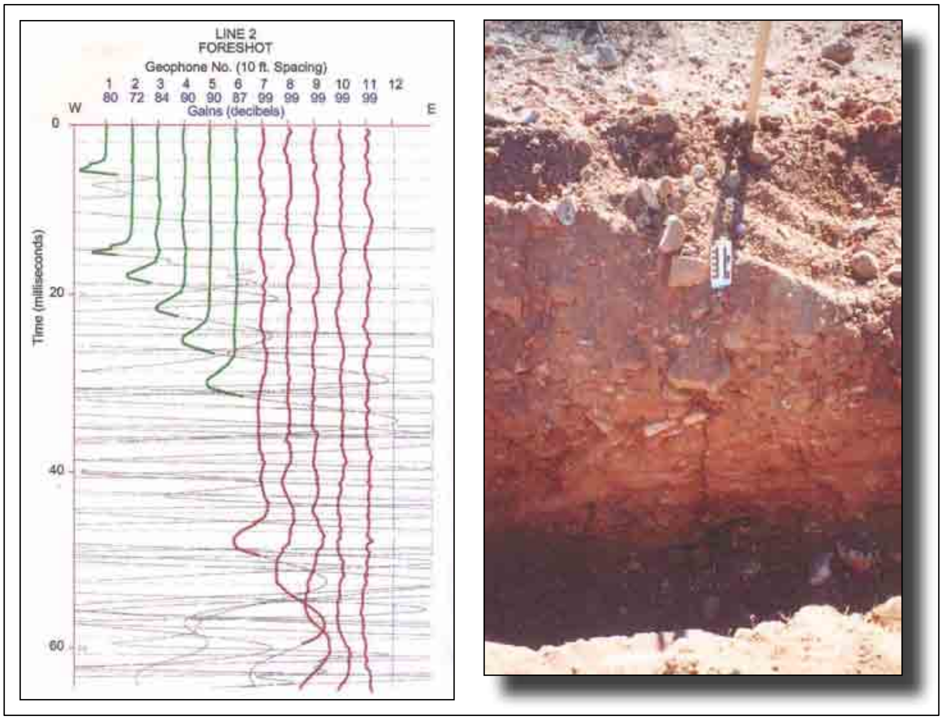

Figure 2. Example seismic refraction traces with used to interpret presence of a possible earth fissure (left), and fissure found in a test pit after being located using seismic method (right). The stake next to the test pit was the marked seismic discontinuity field interpretation. Note that the fissure did not pass through the upper 60 cm of uncemented subsurface material, but was distinct in the underlying cemented horizon.

fied fissures, and sampling of lineaments identified by LSA photo analysis and ground reconnaissance, followed by test pits and trenches for ground truth, was accomplished. Additional seismic lines were then completed on either the upstream or downstream side of the dam where fissures were thought to be a risk. Twelve geophone arrays were used in an overlapping pattern to provide continuous coverage in these areas. Seismic anomalies were interpreted in 33 of 93 seismic lines through the study area. Test pits were used to check or verify 18 of those seismic interpretations, and earth fissuring was verified at nine of those lines. At two lines, the subsurface material, being gravelly and poorly or not cemented, could not hold open visible ground cracks, so that earth fissure identification was not possible. Finally, discontinuities in the cemented soils at the other seven lines were identified but not considered to be earth fissures.

Basin Characterization

Having identified earth fissuring as an imminent risk to the dam, understanding of the local subsidence phenomenon was essential to developing mitigation and engineering a solution to make the dam safe. Documented historic subsidence was limited to changes in the dam crest elevation and a few nearby survey monuments. Data from a deep well more than a mile from the dam that penetrated into deep, rock-like alluvium but not bedrock, was the closest deep-basin alluvium information to the site. To further complicate matters, the groundwater decline history through the basin consisted of two historic trends. Beginning in the 1940s and extending through the mid-1980s, the basin groundwater level declined precipitously, and subsidence proceeded rapidly. By the mid-1980s, the Central Arizona Project (CAP) canal began delivering water from the Colorado River, and groundwater pumping profoundly decreased.

Several surface geophysical methods were then used to assist in developing a useful characterization of the basin geometry and geology. The Arizona Department of Water Resources (ADWR) provided two sets of information to FCDMC that became key to basin characterization. InSAR imagery (Figures 1 and 3) provided quantitative subsidence through the region, including at McMicken Dam, and ADWR per-

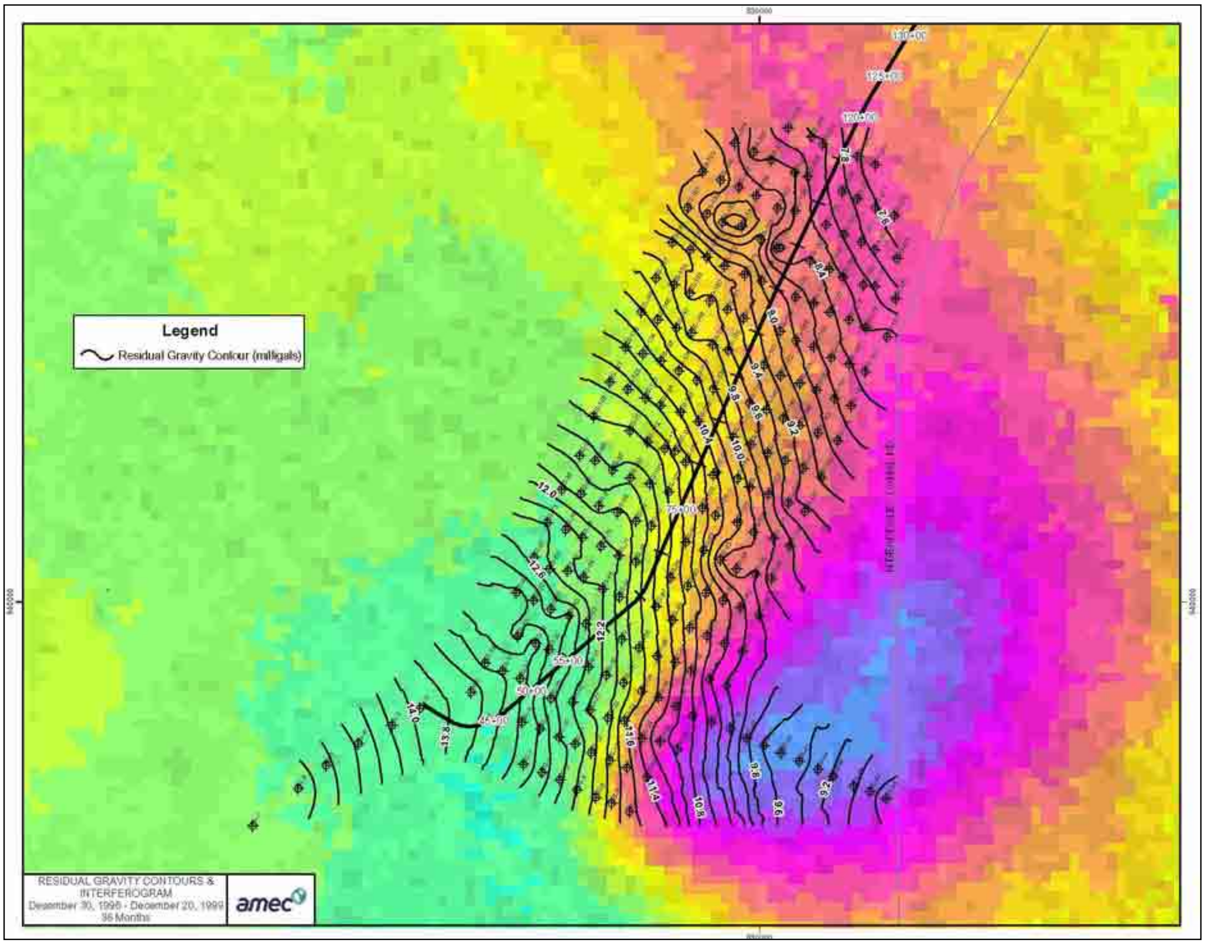

Figure 3. Southern end of McMicken Dam and gravity survey overlaid on InSAR interferogram showing distribution of subsidence between 1996 and 1999. Nearly 3 cm of relative elevation change is indicated from the south end of the dam to the center of the subsidence bowl (blue is at bowl center) to the east. Gravity survey began on bedrock southwest of the dam. About 1.8 miles of dam is shown.

sonnel performed a local gravity survey (Figure 3), using their Scintrex CG-3M gravimeter and Trimble GPS Total Station 4800 for survey control, to assist in better understanding bedrock in the fissure area.

With the bedrock outcrop at the southwest corner as the only control and no funding to drill and geophysically log deep exploratory wells, prospects for effective interpretation of the gravity data was, at first, severely limited. However, having the equipment, software, and a cable with 20-meter geophone spacing, the author's firm performed several deep Refraction Microtremor™ surveys to interpret depth to bedrock at several locations where it was still within about 100 m of the surface. These s-wave bedrock depth interpretations provided several constraint points on the gravity interpretations. In addition, interpreted s-wave velocities were compared with results of historic geophysical logs obtained as part of characterization for the CAP in the eastern Salt River Valley to help estimate alluvial basin material densities for use in gravity modeling. A lack of extensive cultural interference permitted several deep Wenner array resistivity soundings to be completed in the study area. It was hypothesized that the subsidence bowl indicated by InSAR was due to a zone of very clay-rich, very low permeability basin materials. Such a zone could significantly influence subsidence-induced stresses and strains, and would need to be included in a geomechanical model to predict future behavior. An Advanced Geosciences, Inc. Sting R1 resistivity meter and cabling for pin spacings up to 300 m (1000 m total spread distance) were used.

Alluvium with relatively high resistivities, in the range of 40 to 140 ohm-m, was interpreted in alluvium above the groundwater table. Low-resistivity alluvium, with interpreted resistivities of about 6 to 7 ohm-m, was interpreted in several resistivity soundings. Low resistivities were coincident with the InSAR-indicated subsidence bowl east of the dam. Interpreted resistivities in excess of 100 ohm-m, consistent with bedrock, were identified at the bottom of two profiles. Conceptual geologic basin profiles (Figure 4) were developed using the results from the surface geophysics measurements and interpretations. These basin geologic profiles served as the geometric basis for 2-D coupled finite element seepage and stress-strain models that were used to assess historic and potential future ground strains and fissuring potential.

Geotechnical Conditions

The preferred mitigation alternative was abandonment of the south end of the dam where the earth fissures were present, and construction of a new dam extension to isolate that area. Seismic refraction geophysics contributed to the geotechnical investigation both to screen the new alignment for fissures

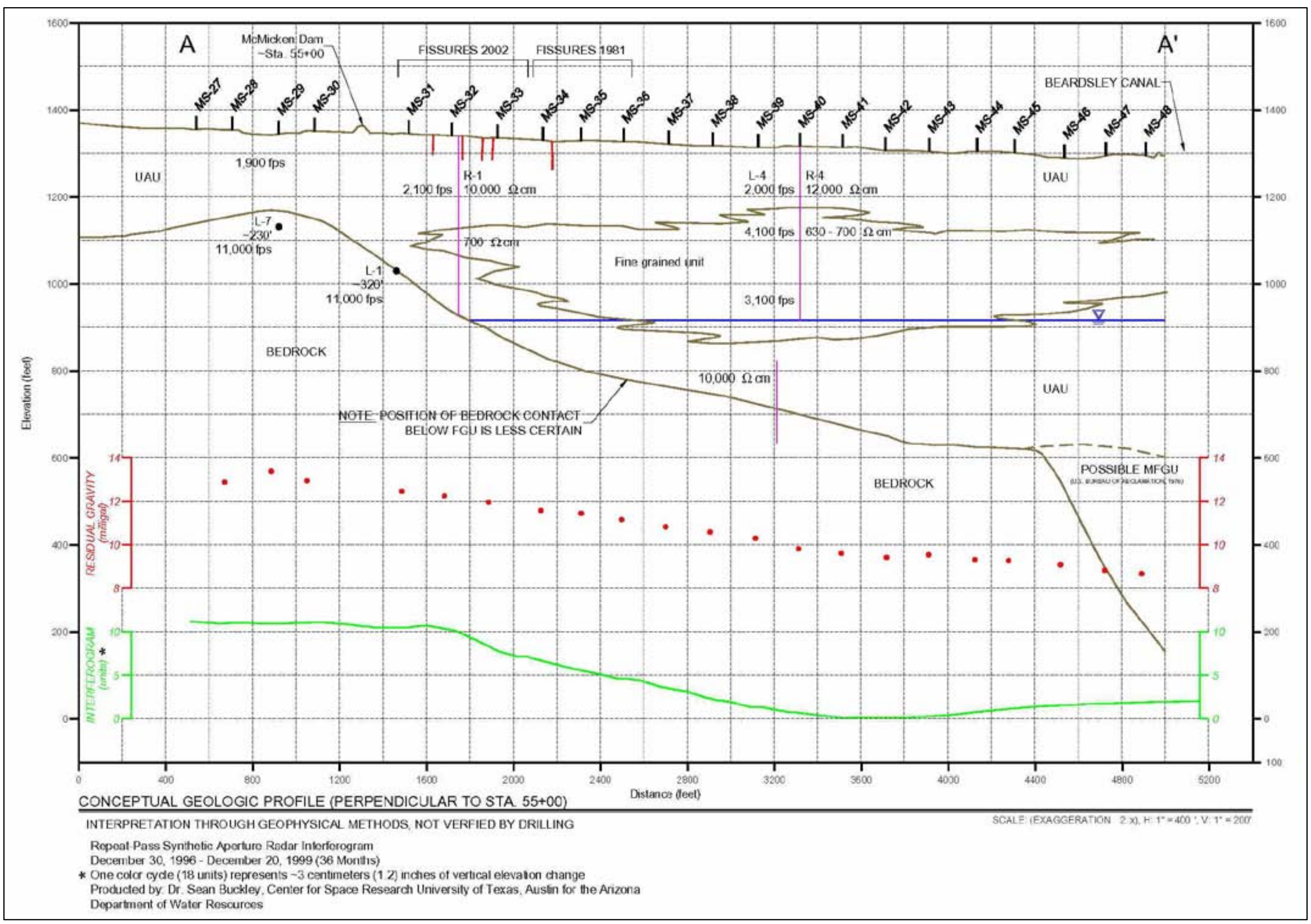

Figure 4. Conceptual basin profiles based primarily on surface geophysics were used to develop finite-element coupled-seepage and stress-strain models to assess current and potential future subsidence and ground-strain conditions (Weeks and Panda, 2004) for dam mitigation, including abandonment of part of the existing dam and design of new dam section.

Figure 5. Test trench at new dam extension demonstrating various cementation conditions characterized with surface seismic (left) and final dam mitigation of extension that avoids earth fissure zone (right). At test trench, the upper horizon (p-wave velocities less than 300 m/s) has been stripped off to the top of a strongly cemented horizon (p-wave velocities 790 to 945 m/s) where backhoe refusal occurred. A larger trackhoe excavated through that horizon into the underlying less-cemented horizon (s-wave velocities 305 m/s). The final new dam extension is the curved section soil cement embankment at the center. The abandoned section in the earth fissure zone is to the upper right.

and to assist, along with surface mapping, borings, and test pits, in developing the geotechnical profile. During the preliminary geotechnical assessment of an initial dam extension location, a buried channel or other deep uncemented to weakly cemented Holocene soil condition was identified in the seismic profile. After verification by test pits, the dam extension alignment was moved. Seismic results along the new alignment indicated that cemented Pleistocene soils were typically present within a depth of 1.5 m or less along the alignment, and were commonly underlain by a softer horizon before more competent material was encountered at depth. These conditions were confirmed by results from test pits and borings (Figure 5). As detailed by Rucker and Fergason (2006), interpreted seismic velocities were also used as a measure of strength and correlated to other geotechnical testing results to assist in characterizing the subsurface profile underlying the dam extension for excavation conditions, resistance to erosion, and piping. Empirical correlations of excavatability and seismic velocity for this and similar projects in these cemented soils are shown in Figure 6.

Experience at other Flood Retention Structures

With mitigation complete, work at McMicken Dam has now progressed to long-term monitoring where surface geophysics, particularly seismic refraction, may be used to assess future conditions or changes on an as-needed basis. To the south of McMicken Dam, White Tanks No. 3 FRS has also suffered significant historic differential subsidence, and a subsidence bowl is apparent at that structure in InSAR imagery (Figure 1). Earth fissures have not been observed at that FRS, and seismic refraction profiling during extensive remediation has not indicated that earth fissures are present. In the eastern Salt River Valley, a new urban freeway alignment has been commingled with the existing Spook Hill FRS. Significant modifications to and reconstruction of that FRS were incorporated into that work. Seismic refraction profiling verified the presence or absence of buried paleochannels in selected areas and provided geotechnical profiling information in other areas. Extensive geophysical engineering work and basin mod-

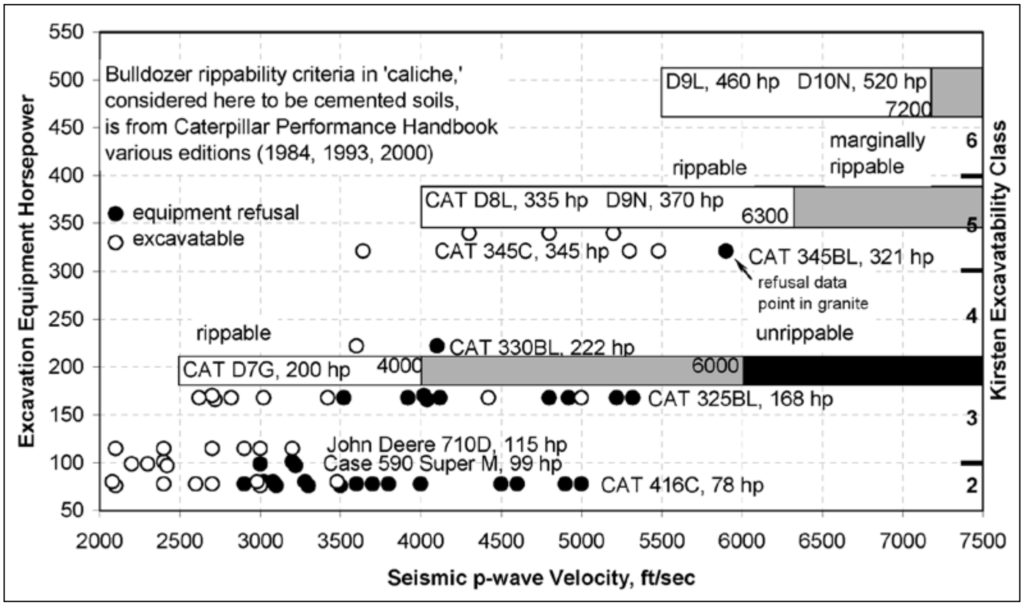

Figure 6. Empirical correlation of backhoe and trackhoe excavation performance in cemented soils in the Salt River Valley area of Arizona at test pits with overlapping seismic lines (modified from Rucker and Fergason, 2006). The Kirsten (1982, 1988) excavatability classification system (excavatability class on right side of figure) has been adapted to address erodability (Annandale, 1995; NRCS, 2001). These correlations can begin to provide a quantitative empirical link from seismic velocity to erodability.

eling using historic deep geophysical well logs has been performed at Powerline FRS in the east Salt River Valley. An earth fissure has been located at that structure; remediation action is in process. The ultimate scope of the work performed at Powerline FRS may be on a scale similar to McMicken Dam. Surface geophysical work in support of geotechnical activities has also been performed at several other dams and flood retention structures in the area.

Conclusion

Geophysical methods are providing critical information for geotechnical assessment and management of flood control dams and other structures. Using non-invasive geophysical techniques as screening and initial subsurface evaluation tools to direct and focus more expensive and invasive drilling and excavating activities is both efficient and cost effective. The typically linear nature of geophysical measurements are particularly compatible with typical linear structure geometries and site conditions. The authors attribute much of the success in applying geophysical methods to these geotechnical problems to the close working relationships and support between the engineers and geologists performing the work, and the facility owners and regulators who depend upon the results of their labors.

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Marine Resistivity Survey of the Panama Canal

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Introduction

hydroGEOPHYSICS, Inc. (HGI) recently completed a 773-line-km marine resistivity survey as part of the ongoing project to update the Panama Canal to accept today's ships. When it opened in 1914, the 77-km-long canal was widely acknowledged as one of the largest, most difficult engineering projects ever undertaken. Disease, landslides, and other problems claimed an estimated 27,500 lives during its construction. Nevertheless, as predicted by the canal's promoters and backers, it immediately became a vital route for international maritime trade. In fiscal year 2008, 14,702 vessels passed through the waterway carrying a total 309.6 million tons of cargo. Once the current expansion is complete, the annual tonnage passing through the canal is estimated to double.

Most of the Panama Canal traverses Lake Gatun, a man-made, fresh water lake 26 m above mean sea level. The 26 m of hydraulic head is sufficient to reduce the influence of seawater intrusion and saturation variability within the zone of interest.

The depth and width of the current channels will be increased. A new channel and a third set of larger locks will be added. The new locks and channels are slated to begin operation in 2015. The Panama Canal Authority (ACP) elected to perform a marine resistivity survey as an effective way to augment the engineering property information obtained from geotechnical borings of the soil and rock to be dredged.

The resistivity survey was designed to characterize the surface of the canal floor to a depth of 8 m given an average water column of 15 m. Resistivity data were densely sampled along transects spaced 25-m apart with an average channel width of 320 m along the majority of the canal and the adjacent Atlantic approach.

2-D and 3-D marine resistivity model results derived from the streaming resistivity data were correlated to geotechnical boring information through regression and spatial analysis to predict the lithologic and engineering properties beyond the limited region near boreholes. The lithologic and hardness maps derived from the resistivity survey will be used by the dredging companies to design and manage their dredging configuration and deployment with the goal of reducing risk and cost.

Resistivity Data Acquisition

To better manage the logistics of data acquisition within an active shipping lane, as well as for safety considerations, the canal was parsed into 15 survey regions. Each region consisted of multiple closely spaced traverses (25 m, nominally) using a dipole-dipole array configuration with 15-m electrode separation. A specially constructed floating electrode marine streamer cable providing dipole separations of n=1 through 8 was towed at a constant survey speed of 2 to 3 knots, subject to wind direction and wave conditions. A SuperSting R8 resistivity system made by Advanced Geosciences, Inc. (AGI) was used to acquire the data in a streaming mode (Figure 1). Each resistivity measurement was synchronized to a combined GPS/sonar network to obtain a data package that includes position, time, altitude, speed,

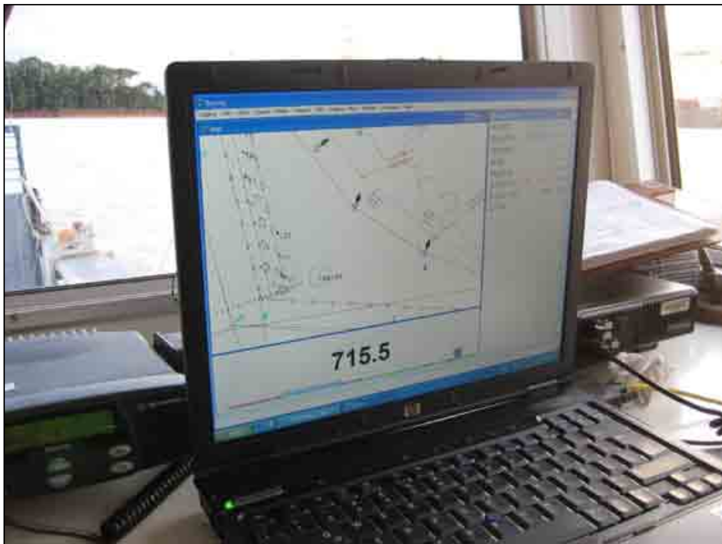

Figure 1. Marine resistivity equipment.

and heading along with water conductivity, depth, and temperature. The Hypack hydrographic survey software was used for navigation guidance.

Marine resistivity methods are subject to numerous sources of coherent noise such as shipboard electronics and ground loops between the resistivity cable and meter. Nearby marine infrastructure and ships may also produce noise from corrosion protection systems and other sources. A typical received waveform (Figure 1) exhibits coherent noise superimposed on the idealized transmitted waveform.

The SuperSting allows for auto ranging based on received signal strength. For marine applications, auto ranging is primarily controlled by surface water conductivity. The cycle of each measurement is selectable between 0.4 and 14.4 s. Streaming dipole-dipole surveys inherently require continuous forward movement of the array. Therefore, stacking individual readings is not possible due to limited amount of time available to make each measurement. With survey speed and data quality in mind, a 0.8 millisecond (ms) cycle time was used as a trade-off between noise and spatial data density. For a constant survey speed of 2 to 3 knots, the faster cycle times produced a spatial data density sufficiently high with which to evaluate the continuity between adjacent measurements and other data quality indicators. Data measured in locations near sources of noise indicated that short sample times captured more coherent noise.

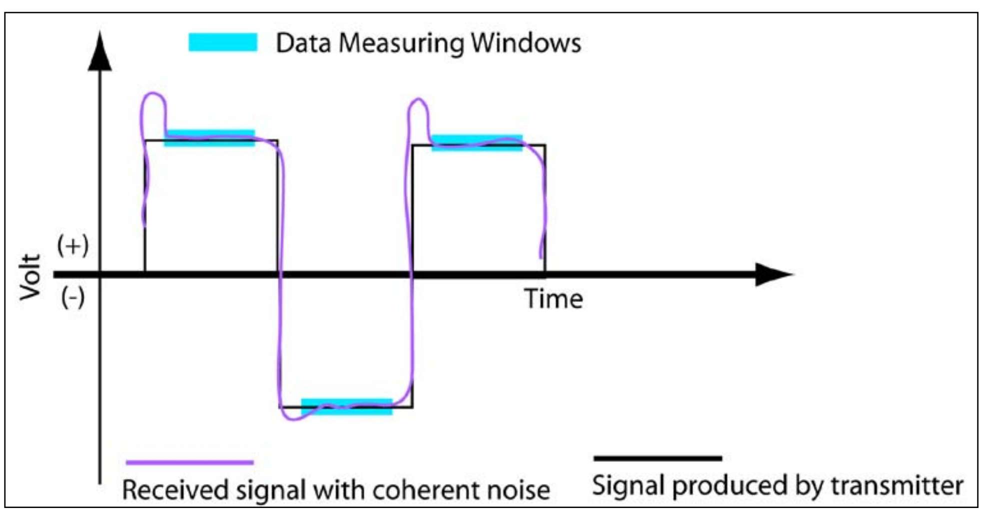

Figure 2. Signal and noise during a marine resistivity survey.

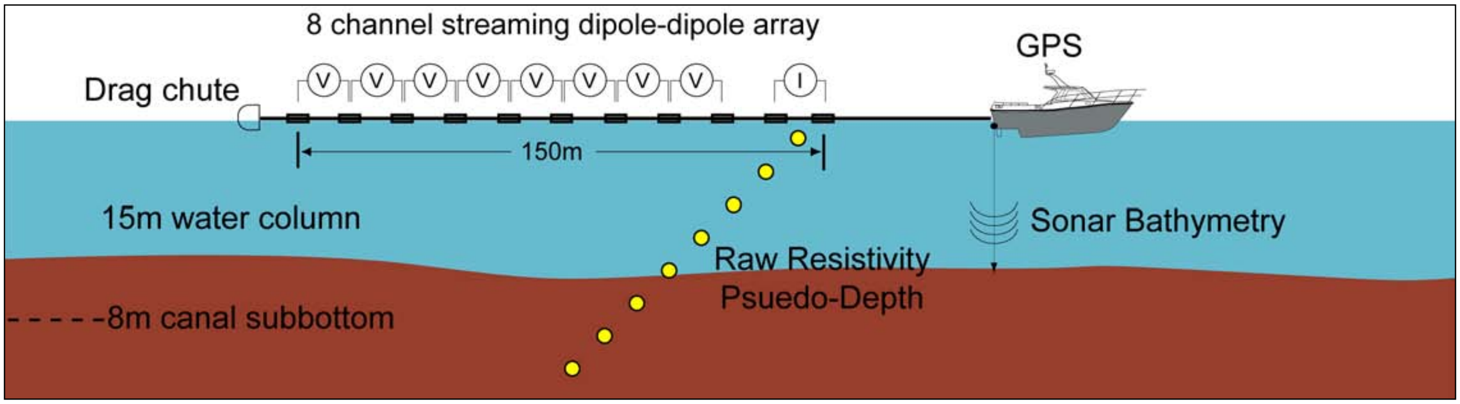

Figure 3. Schematic of streaming marine resistivity system.

In post processing, the position of the electrodes was obtained by interpolating between the path of the ship and the cable. At a survey speed of 2 to 3 knots and with low wind and currents, the cable and drag chute closely followed the path of the ship. Data were collected using low-profile floats to reduce wind drift and only when the survey ship's path and cable were co-linear and under sufficient tension.

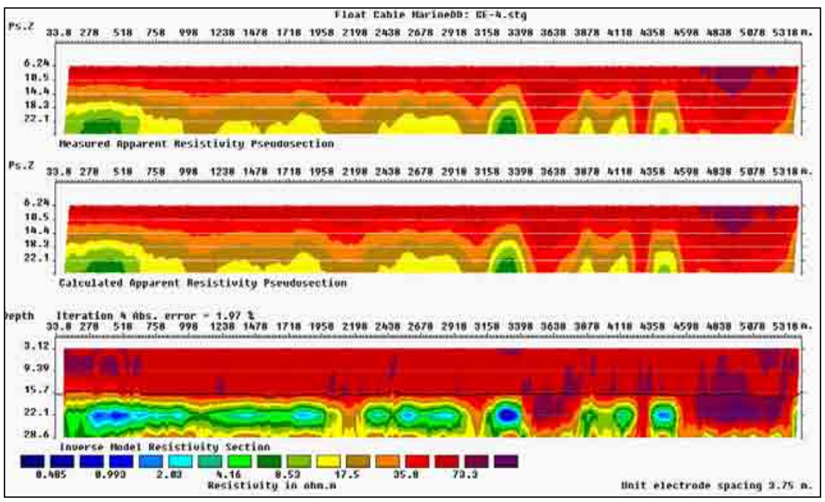

Figure 4. RES2DINV output presentation showing observed apparent resistivity (top), calculated resistivity (middle), and model section (bottom) with a black line indicating depth of water.

Data Processing

The observed data were inverse modeled using RES2DINV marine inversion code (Geotomo, Inc, Malaysia) to obtain a resistivity versus depth section for each of the 307 transects. Figure 4 is an example output showing observed and calculated data along with the corresponding model resistivity section. The black line in bottom section indicates the depth of the water later. In general the resistivity results showed a two-layer system, with the upper layer exhibiting higher resistivity values than the lower layer. Additionally, the data tend to be very clean and model RMS errors were low.

Geotechnical Analysis

A total of 1260 borehole logs were provided to HGI. The data were entered into a database, where up to 15 parameters were available for recording. Several challenges were encountered when dealing with the borehole data, including the large time span over which the boreholes were drilled (1940s to present), categorical and ordinal parameter data (resistivity is considered continuous data), most data were fuzzy (for example, data were recorded with qualifiers of "very" and "moderate"), and parameters were inconsistently recorded. However, the most challenging aspect was the canal had changed (dredged or widened) since the boreholes were emplaced and many boreholes were on shore at the time of drilling.

The canal undergoes continuous maintenance to ensure a sufficient depth is maintained for the large cargo ships.

Results

The higher spatial density resistivity model results were correlated to more sparsely distributed borehole data using regression models that included material type, hardness, and other parameters. These models were then used to transform all resistivity data to the borehole parameter to predict lithology type between boreholes.

Figure 5 shows several of the boreholes overlain on a resistivity section. The present-day bathymetry is shown in blue. For this example, the borehole material type was lumped into overburden (loose sediments), weathered rock, and hard rock. The GAM-series boreholes were placed in the mid 1970s, and several were on shore (GAM-003, GAM-005) or in shallower water (GAM-012 and GAM-013) at the time of drilling. The borehole data that were recorded and subsequently removed are shown as half blocks above the water line.

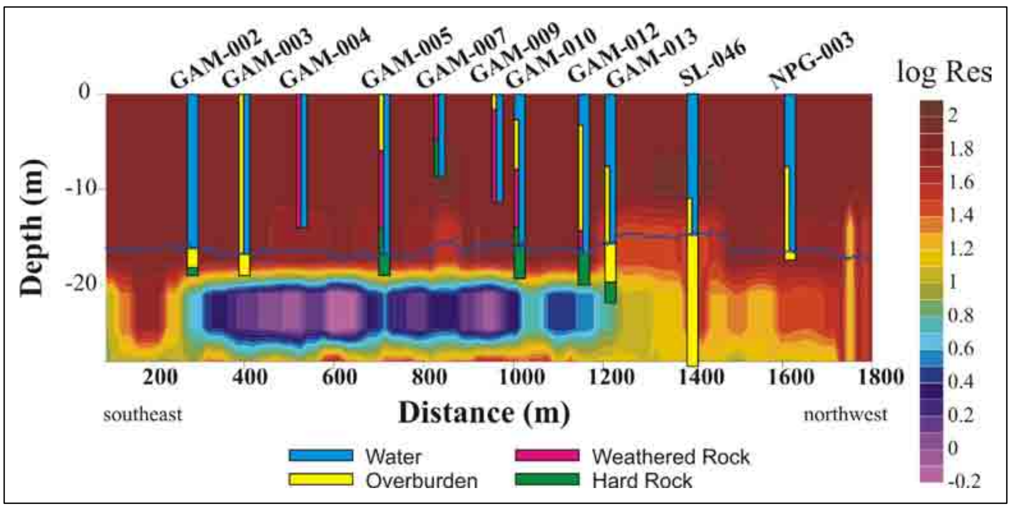

Figure 5. Example of co-located borehole and resistivity data on the Gamboa region. Borehole drilling spans from 1943 to the present and indicates water levels at the time of drilling which in many cases was before current canal floor dredge depths (blue line).

For final processing, the lithology data were separated into bins designated as clay, silt, sand, and rock fractions. This designation focused more on the soft sediments and lumps the weathered saprolite and hard rock into one bin. The material type bins were then converted to a numerical value to facilitate the regression modeling. These numerical values were assigned a rank by sorting the average electrical resistivity in ascending order. For example, within the upper layer the ranking order from low to high resistivity is silt, rock, sand, and clay. For the deeper layer, the ranking order is rock, silt, clay, and sand.

The scatter plot of Figure 6 shows the distribution of electrical resistivity for four material types. The range of resistivity values at co-located borehole resistivity lines is relatively narrow, making the comparison to material type tenuous. Although the correlation of co-located resistivity and borehole data is poor, a first-order approximation can be made based on the average behavior of the material type, which shows a trend of increasing resistivity with material type. The average resistivity within each material type is plotted using a red square for the lower layer and a blue diamond for the upper layer. The linear regression analysis was performed on this average resistivity. The correlation coefficient for the average resistivity is 0.99 and 0.92 for the upper and lower layers, respectively. The error bars are for one standard deviation from the mean.

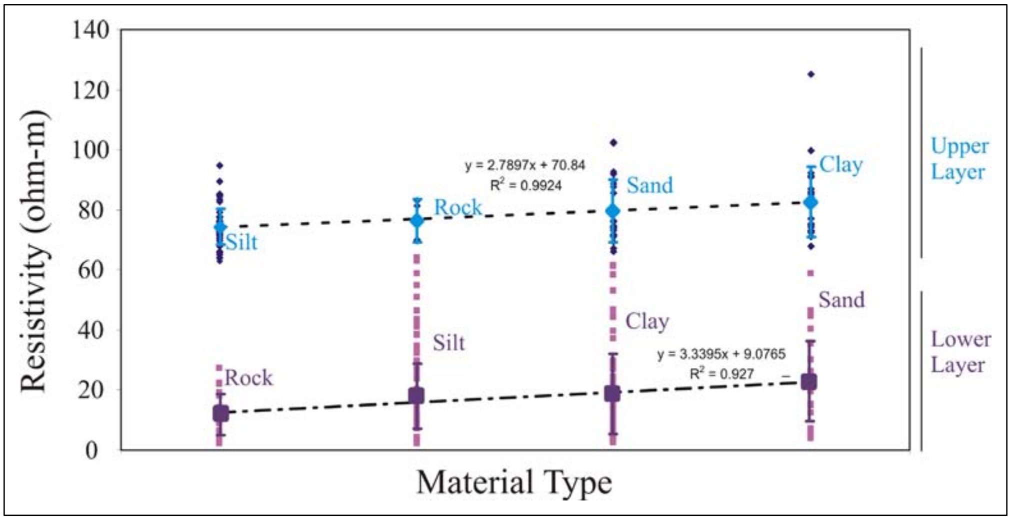

Figure 6. Scatter and regression of material type and electrical resistivity.

Upon transformation, the geotechnical data were presented as a horizontal slice of color contours at different depths below the water surface showing the distribution of materials. Figure 7 is a map of the distribution of the material type for the Gamboa region of the canal. In addition, a material hardness analysis was performed and presented using similar methods.

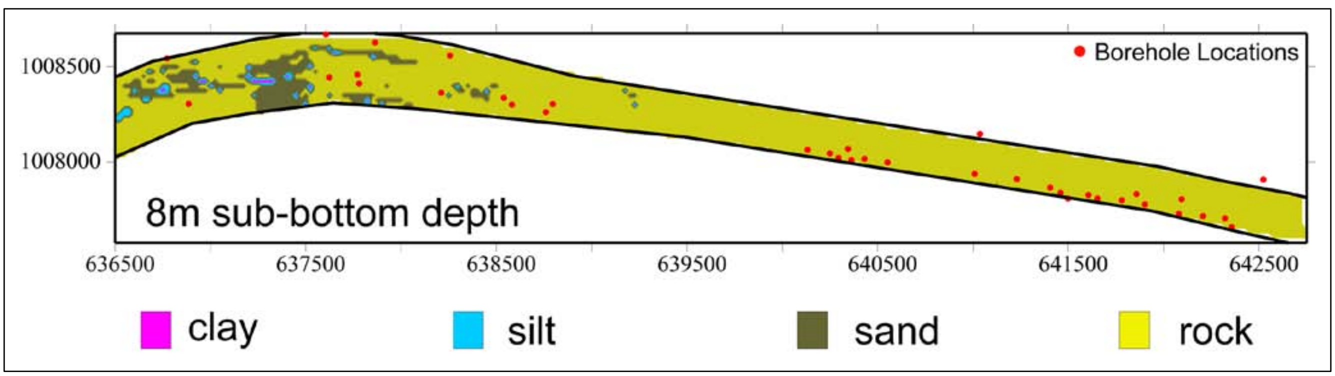

Figure 7. Example of material type conversion from a depth slice at 8 m below the canal floor.

Summary

Through the use of statistical analysis of distribution of resistivity correlated to lithologic and hardness obtained from geotechnical borings, we were able to develop a map of the sub bottom distribution of materials and key material parameters. The maps are being used to plan and configure the dredging activities. Initial reports from suction dredging activities have confirmed the soft sediment predictions from the resistivity data in select areas of the canal.

Acknowledgments

A project of this magnitude can only be successful through the dedication and determination as well as the combined knowledge and talent of a team of individuals. We acknowledge the contributions and hard work of Gillian Noonan, Seth Gering, and Danney Glaser of hydroGEOPHYSICS to this project. In addition, we wish to recognize and Alyssa Kohlman of Tetra Tech, Inc., Golden, Colorado, for providing the geotechnical engineering support and analysis.

Geophysical Methods for Unknown Foundations

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Summary

This article presents a case study on the use of geophysical methods for determining the length of auger cast piles at St. Joseph Hospital, Savannah, Georgia. An expansion plan of the hospital involves adding one additional floor to the existing building. It is known that the building is supported on auger cast piles, but no reliable information is available about the length and design capacity of the piles. Several geophysical methods were successfully used to determine the pile length and evaluate pile capacities. These methods included the impact echo method, the parallel seismic testing method, and the magnetometer method. Following a well-planned testing program, all these methods were successfully conducted at the site. The methods were found to give comparable results in estimating the length of auger cast piles. Results were incorporated with information from the site investigation to provide reasonable estimates on the bearing capacity of the existing foundation. This case study demonstrates the benefits of incorporating geophysical methods in engineering design.

Introduction

St. Joseph's Hospital is located in Savannah, Georgia. The hospital is planning to add a floor to the existing one-story building. The one-story building comprises two portions: a structure built in 1966 attached to another structure built in 1974. The entire building is supported on a deep foundation consisting of augered cast-in-place (ACIP) piles. The additional floor will add load to the pile foundations and therefore it is very important to determine if the design capacities of existing ACIP piles could support additional loads. Information about the lengths and design capacities of ACIP pile can no longer be located. Non-Destructive Testing (NDT) methods were used to determine the pile lengths and then the pile design capacities were estimated based on the pile lengths and subsurface information collected through cone penetration test (CPT) soundings performed near the piles. Through the NDT methods, the physical characteristics of ACIP piles were determined without damaging them. Three different NDT methods were used to determine the pile characteristics, including parallel seismic, pulse echo, and magnetometer methods. These methods provided consistent results of pile characteristics. This, in conjunction with results of geotechnical investigation by CPT, was used to determine the bearing capacity of the existing foundation.

Geotechnical Site Investigations

CPT soundings and geotechnical data at the site indicate that the subsurface primarily consists of medium dense sands (SP), clayey sands (SC), and silty sands (SM) in the upper 64 ft (20 m). Groundwater was present at depths of 8 to 10 ft (2.4 to 3 m) below the ground surface. The general subsurface profile is summarized in Table 1.

Table 1. General subsurface conditions at the site.

Depth (ft)	Soil Description	USCS Classification	Average Tip Resistance, tsf	Average SPT Blow Count
0 to 65	Medium dense sands, silty sands and clayey sands	SP/SC/SM	74 to 95	18 to 21

Figure 1 shows an example of the measured results using a cone penetrometer equipped with a pore pressure measurement unit (CPTu) and standard penetration test (SPT). These include the variations of tip resistance, side friction, pore pressure, and SPT blow count with depth. Locations with high pore pressure typically correspond to clay layers.

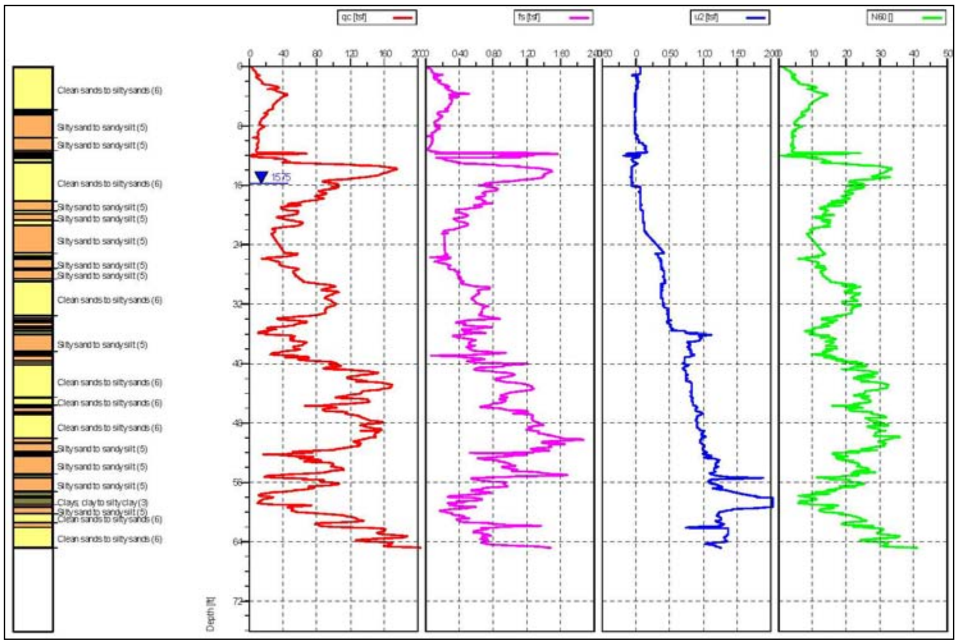


Figure 1. Example results of SPTu and CPT test.

Field Geophysical Testing Program

Parallel seismic tests, pulse echo tests, and magnetometer tests were performed for piles installed below column A3 of the 1966 building and column A19 of the 1974 building (Figure 2). Figure 2 also shows the locations of NDT tests in reference to the buildings. To perform the NDT tests, the upper soils below the pile cap and around the piles were removed manually at both outside and inside the walls (Figure 3). The dimensions of pile caps and piles were measured and are shown in Figure 2.

Pulse Echo

Pulse echo method (PEM) tests, also known as low strain pile integrity tests, are performed using the pulse echo tester (PET) module of the PISA system. The test consists of attaching an accelerometer to the top of a deep foundation member. By striking the deep foundation top with a hand-held hammer, waves are generated and recorded by the accelerometer. Figure 3a shows a typical PET using the PISA system. Several of these waves are recorded for further analysis. Pile integrity is determined based on the behavior of the recorded waves.

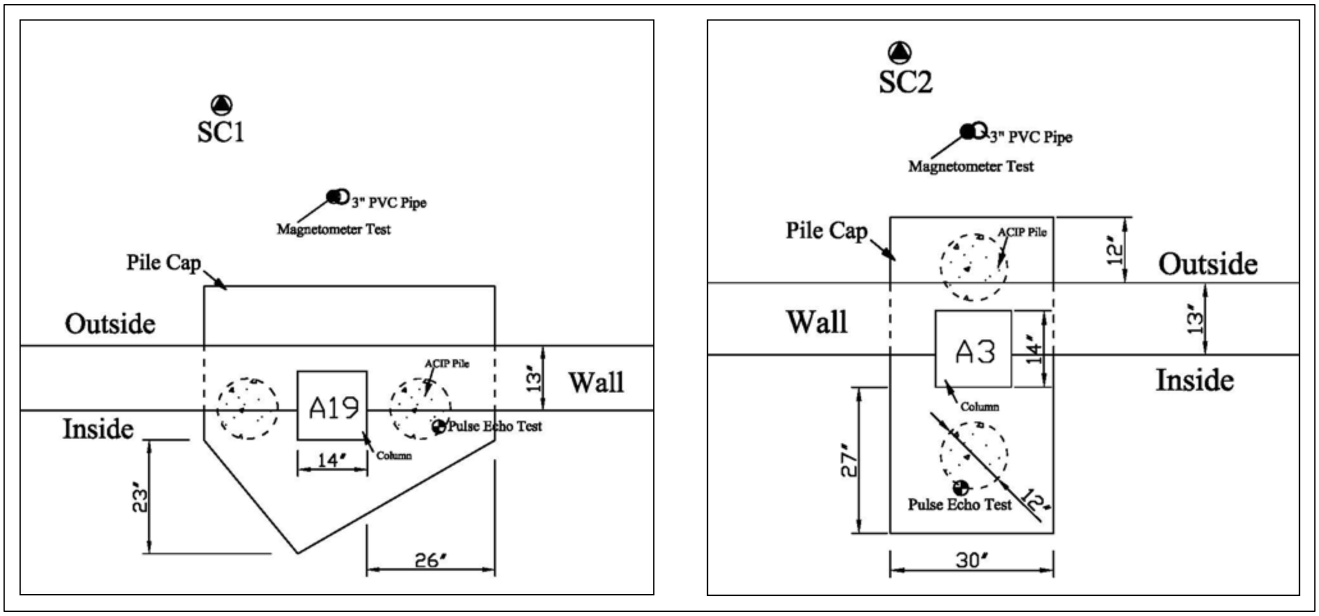


Figure 2. Plane view of columns A3 and A19 and their relationship to locations of drilled shaft.

PEM testing was conducted on August 11, 2006 at three pile cap locations (A-19, A-3, and B-3). Two testing locations on each of the pile caps, designated A-19, A-3, and B-3, were performed.

The PEM testing analysis is based on compressional wave speeds of 11,000 and 13,000 ft/s (3350 and 3962 m/s). This range was used to bracket the wave speed of grout in the auger-cast piles because the actual mix is unknown.

The PEM test results for pile cap A-19 (Figure 4) show a significant impedance change between 37.8 ft (11.5 m) and 45.8 ft (14.0 m), respectively for wave speeds of 11,000 and 13,000 ft/s (3350 and 3962 m/s). This change in impedance is likely the pile tip. Note that these depths include the thickness of the pile caps and should be subtracted to get the actual auger-cast pile lengths. Pile cap thickness

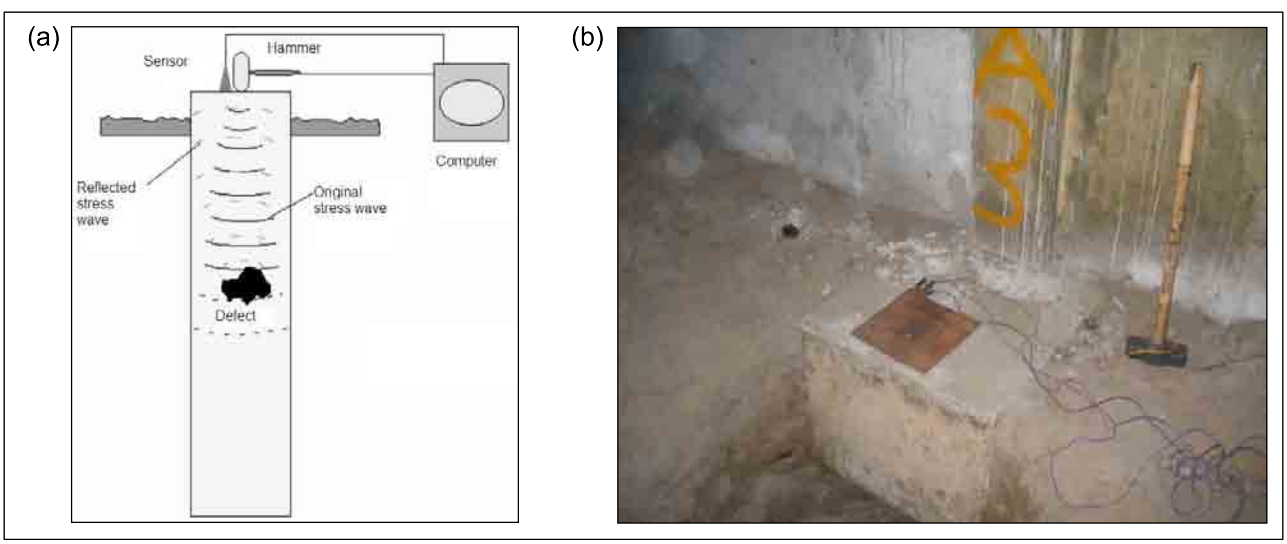


Figure 3. (a) Schematic of pulse-echo test; (b) system components.

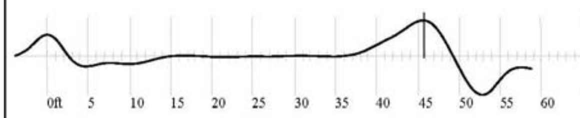
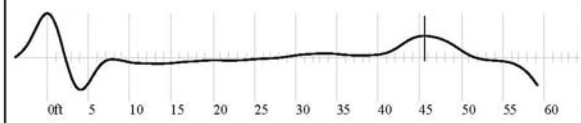
Pile Cap Column Line Intersetion	Date of Test	Reflectogram (feet)	Depth (ft) / Wave Speed (ft/sec)
A-19 (1)	**8/11/06**		45.8 / 13,000
A-19 (2)	**8/11/06**		45.7 / 13,000

Figure 4. Example of pulse-echo signal after processing.

is anticipated between 2 and 3 ft (0.6 to 0.9 m) as observed in the small excavation around caps. The PEM test results for pile cap A-3 show an impedance change between 42.1 and 49.6 ft (12.8 and 15.1 m), respectively for wave speeds of 11,000 and 13,000 ft/s (3350 and 3962 m/s). This change in impedance is likely the pile tip. The PEM test results for pile cap B-3 show no conclusive results; further pile cap preparation is required.

Parallel Seismic Tests

Parallel seismic tests are performed by pushing a cone penetration test with a seismic element (SCP-Tu) adjacent to a foundation element. Striking the foundation element to generate shear waves, the SCPTu can measure the arrival time of the waves. Performing this test at repeated intervals, the length of unknown foundation elements is determined. Figure 5a shows the setup of a typical parallel seismic test. The SCPTu extends beyond the embedment depth to determine the soil type and strength data of the bearing stratum. This test can be performed for concrete, wood, masonry, or steel foundations.

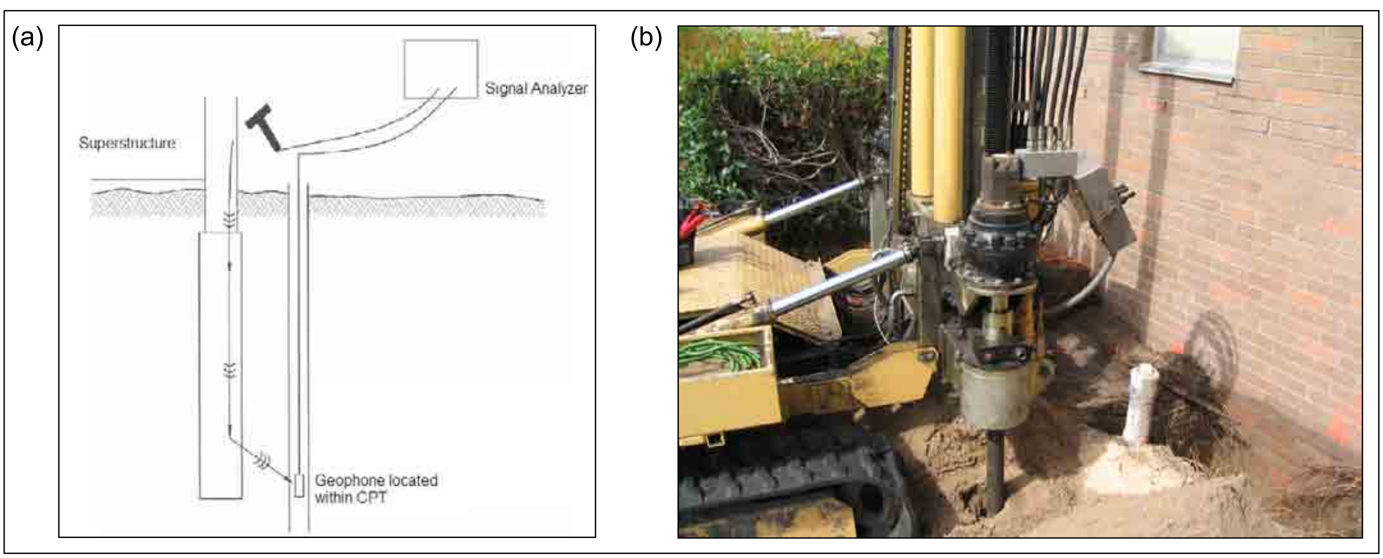


Figure 5. (a) Schematic of parallel seismic testing; (b) parallel seismic test using seismic CPTu.

Parallel seismic tests were performed at a distance of approximately 3 ft (1 m) from the exposed pile cap near columns A3 and A19 outside the buildings (Figure 2). A steel plate was installed on the top of the exposed pile cap and seismic waves were produced by striking the steel plate with a hammer. A CPT cone instrumented with an accelerometer was pushed into the ground to record the seismic waves at a depth interval of every 3 ft (1 m) to a depth of 65 ft (20 m).

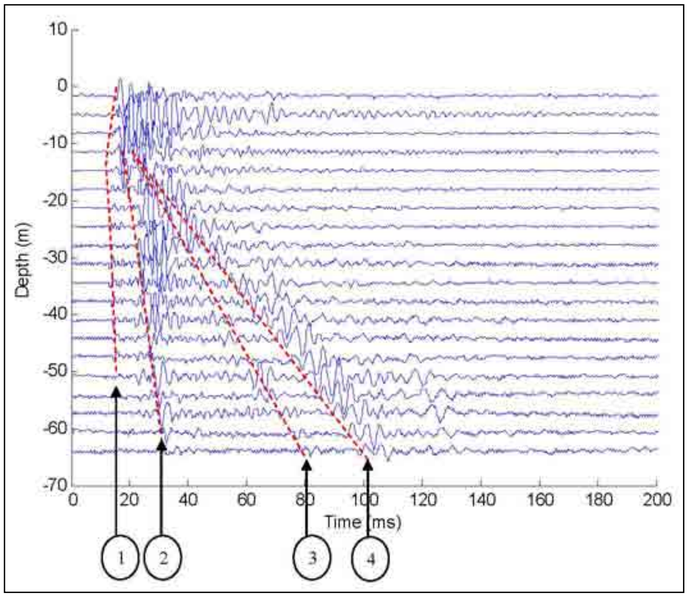


Figure 6. Signals from parallel seismic testing with wave trains identified.

Figure 6 shows the processed signals with four major wave trains identified. Estimation of the pile length from the parallel seismic testing can be conducted by observing the change of the propagation speed of the first wave train, or it can be estimated by observing the change of the amplitude of the wave train before and after exceeding the toe of the pile. The latter approach works when the energy of impact source is controlled or the signals are acquired using a string of geophones with the same impacting source. From the testing data collected at column A3 (Figure 2), the first wave train can be clearly observed up to a depth of 47.6 ft (14.5 m). This implies that the drilled shaft is at least that long. Testing data collected at column A19 further validated this assessment. The recorded signals show that the first wave train from the parallel seismic testing at column A19 can be clearly identified to 50.1 ft (15.2 m).

Magnetometer Tests

A magnetometer can be used to measure the length of rebar in a foundation pile (Figure 7). The Earth is a huge magnet. The rebar is magnetized under the Earth's magnetic field and behaves like a magnet. The presence of rebar can be detected by measuring the induced magnetic field with a magnetometer and therefore the pile length can be estimated based on the length of the rebar. In this method, a magnetometer is inserted into a non-metallic pipe installed in parallel with the pile. As the rebar has a great length-to-diameter ratio, the induced magnetic field strength is relatively uniform within the length of the rebar, but experiences considerable variation (increase or decrease) at the end. This feature can be used to detect the toe of rebar and thus the length. Theoretically the location with the most rapid change of induced magnetic field strength corresponds to the tip of rebar.

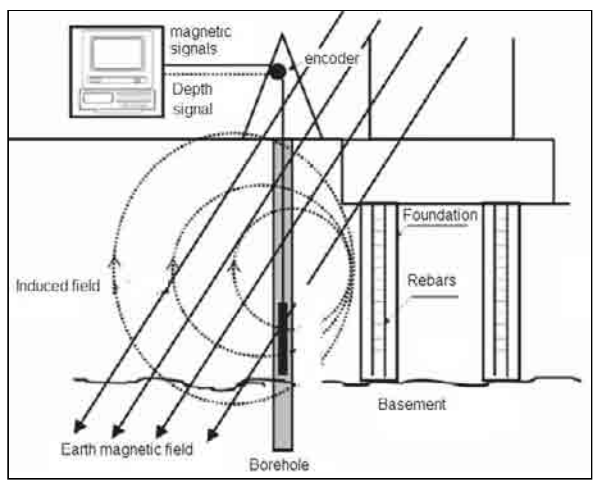


Figure 7. Schematic illustrating use of a magnetometer for pile-length determination.

Prior to the magnetometer tests, two 3-in (8-cm) PVC pipes were installed at two boreholes drilled near pile caps at columns A3 and A19 at a distance of approximately 2 ft (0.6 m) from the pile cap (Figure 2).

The PVC pipe installed at column A3 has a total length of 70.5 ft (21.5 m) with a 36-in (0.9 m) section extruded above the ground, while the PVC pipe installed at column A19 has a total length of 68.5 ft (20.9 m) with a 21-in (0.5-m) section extruded above the ground. The bottoms of both PVC pipes were sealed and filled with water. During the tests, a magnetometer with an 80-ft (24-m) cable was lowered into PVC pipes to a depth of 70 ft (21 m). The magnetometer readings were taken continuously while inserting (downward) and withdrawing (upward) the cable. We used a mini-Gauss magnetometer comprising a sensor tip, a cable, and a digital display. The sensor tip, placed in the vertical direction, detects the vertical component of the magnetic field.

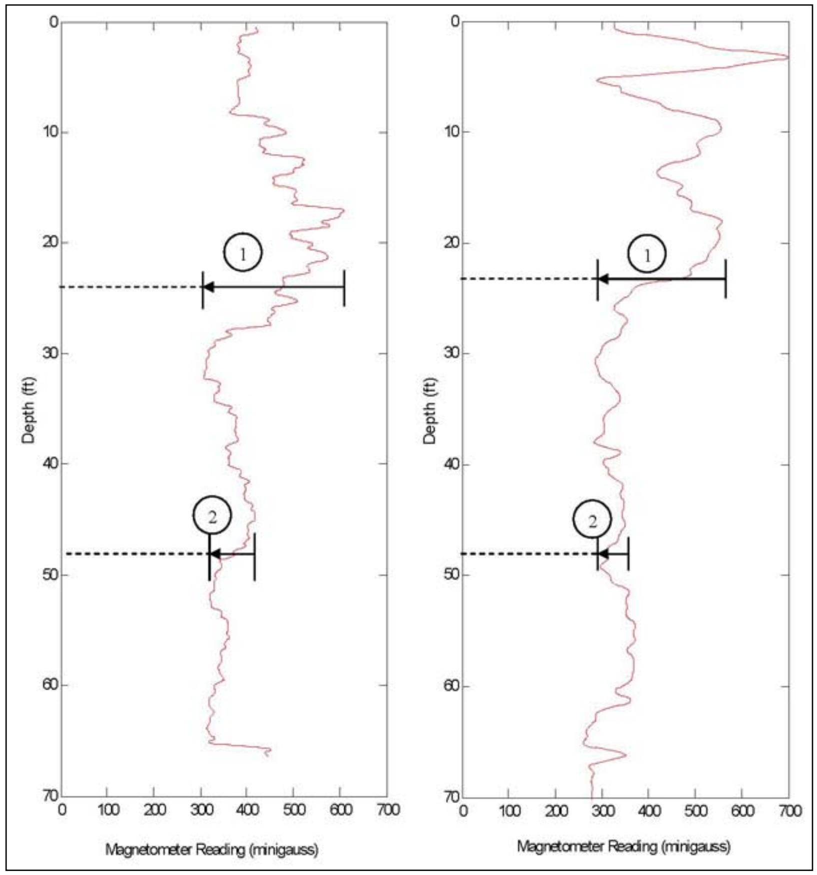


Figure 8. Magnetometer reading with depth at column A3 (left) and A19 (right).

The vertical magnetic field strength was measured at columns A3 and A19 in downward and upward directions. The readings in the upward direction were believed to be less reliable; only the magnetic field strength measured in the downward direction was analyzed (Figure 8). The curves were smoothed to remove noise and help to reveal the general trends of magnetic-field change. A comparison of results at the two locations indicates different patterns of magnetic field strength in the upper 15 ft (5 m), but similar trends at greater depths. An appreciable drop in the magnetic field strength is observed at depths of 20 to 30 ft (6 to 9 m) below the ground surface. The rate of change in the magnetic field strength is greatest at depths of about 23 ft (7 m). Another appreciable drop in magnetic field strength occurs at depths of 44 to 50 ft (13 to 15 m) below the ground surface. The rate of change in the magnetic field strength reaches a maximum at a depth of about 48 ft (14.6 m). At 66 ft (20 m), the magnetometer readings rapidly increased.

The different behaviors of magnetic field strength in the upper 15 ft (5 m) might be due to the interference from the steel cage typically found in auger cast piles, steel reinforcement in the pile cap, or the floor of the building. The test data imply that more reinforcement might be present at column A19. The reduction in magnetic field strength at about 23 ft (7 m) could be caused by the reduction of pile reinforcements, which is common during installation of ACIP piles. The lower drop in the magnetic field strength at about 48 ft (14.6 m) should correspond to the termination of rebar. The rapid increase of magnetometer readings at about 66 ft (20 m) could be due to the magnetometer reaching the bottom of the PVC pipes, changing the sensor-tip orientation and causing a spike in the readings.

The magnetometer test results indicate that (1) the magnetometer detected changes in the magnetic field induced by rebar in piles; (2) there is a change of reinforcement at depth of about 23 ft (7 m); and (3) the reinforcement of pile ends at a depth of about 48 ft (14.6 m).

Table 2. Length of drilled shaft determined by NDT methods.

Location	NDT Test	Depths
Column A3	Parallel Seismic Test	65
Column A3	Pulse Echo Test	55
Column A3	Magnetometer Test	60
Column A19	Parallel Seismic Test	65
Column A19	Pulse Echo Test	50
Column A19	Magnetometer Test	60

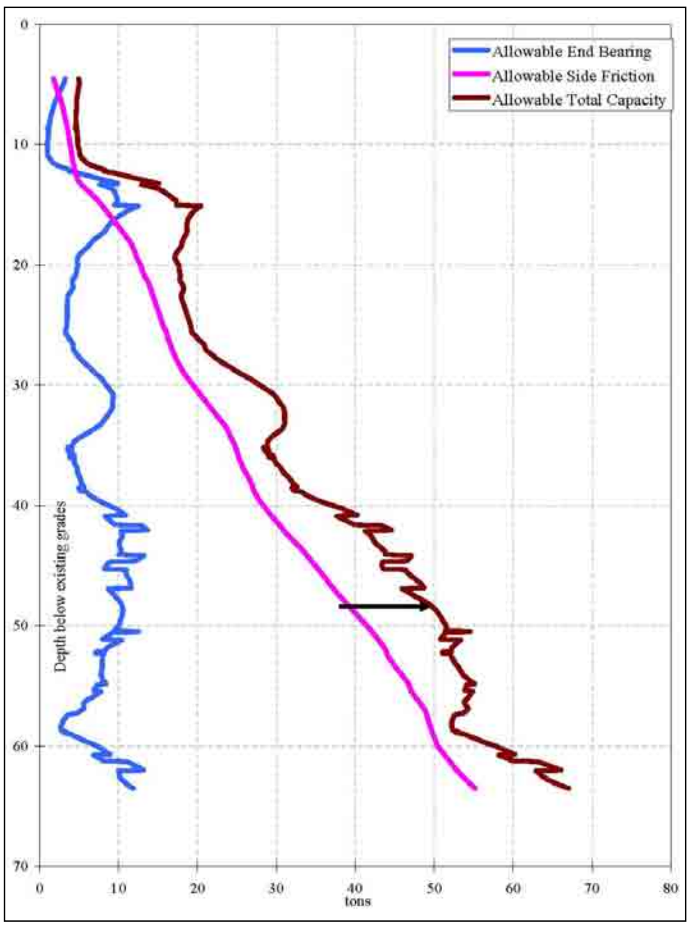


Figure 9. Pile net bearing capacity with depth using French method.

Pile Length and Pile Capacity

The length of drilled shaft determined by different NDT methods is summarized in Table 2. The analysis of three NDT test results suggests that the ACIP piles are embedded to depths of 47 to 50 ft (14.3 to 15.2 m) below existing grades. After excluding the thickness of pile caps, the ACIP pile should have an embedment length from 44 to 47 ft (13.4 to 14.3 m). To be conservative, we recommended a pile length of 44 ft (13.4 m) be considered when calculating pile-design capacity. The pile capacity is calculated using the LCPC method (French method) based on CPT sounding data at two locations (Figure 9). Based on our analysis, the existing ACIP pile should have an allowable compression capacity of 50 tons with a safety factor of 2. An uplift capacity of 30 tons may be used for the addition design. Based on the thickness of the pile caps, it appeared that the piles were embedded more than 12 in (0.3 m) into the pile cap, so the piles should behave similar to piles with a fixed-head connection. A lateral design load of 12 kips was recommended for an allowable pile-head deflection of 0.25 in (0.6 cm).

Summary

This article introduced the application of geophysical methods to nondestructively determine the length of drilled-shaft foundation. These methods (pulse echo, parallel seismic, and magnetometer) gave consistent results for drilled shaft length estimation. This information was used with geotechnical investigations to estimate the bearing capacity of the foundation. Geophysical methods played an important role in assisting the decision by the property owner on the expansion plan. To ensure the successful application of geophysical methods, a well-planned testing program and sound interpretations of geophysical signals are critical.

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Use of Borehole Geophysics to Support Bedrock Design for Highways

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Introduction

Dawood Engineering became involved in a project involving highway widening and installation of new traffic signals at a project near Avoca, Pennsylvania. The T-shaped intersection involved one roadway crossing a bridge to the intersection, while the second roadway was along a hillside. To improve visibility and make room for traffic-light standards, part of the hillside will require removal. The slope of the final rock cut depends on geologic structure. Normally, these data can be collected from outcrops. In this instance, outcrop information was very poor, and the integrity of outcrop measurements was questioned by geologists working on the project.

In designing a rock slope, information about the orientation of discontinuities such as bedding planes, joints, fractures, and faults along the existing hill slope and proposed rock cut is required to evaluate their effects on the proposed cuts.

Geology

The project area is underlain by Pennsylvanian Llewellyn Formation bedrock. Mapped in eastern Pennsylvania, this formation was previously known as the “coal measures” and the post-Pottsville rocks. It is composed of interbedded sandstone, siltstone, and conglomerate, which are medium- to coarse-grained and light gray to brown. It contains coal and dark gray to black shales. The formation has a reported maximum thickness of 250 m. The Llewellyn was deposited upon a broad plain with sediment-choked rivers delivering detritus from the eroding uplands that were located to the southeast. Fluctuations in sea-level, coupled with the shifting nature of the rivers and highlands allowed dense forests to grow on the broad plain. As a result, a large amount of organic matter was buried and eventually turned to coal.

Figure 1. Photograph of outcrop along SR0011.

Bedding is moderately well developed. Coal and shale are thinly bedded. Sandstone, siltstone, and conglomerate may be thick to massive. Joints have a blocky pattern. They are moderately well developed, moderately abundant, moderately spaced, regularly sequenced, steeply dipping, and open. The formation is slightly to moderately weathered from a shallow to moderate depth. Depending on lithology, rubble consists of small to medium, flat, elongate fragments to large blocky fragments. The overlying mantle is thin to moderately thick. The formation forms low ridges and valleys in rolling terrain. Natural slopes are stable at moderate angles.

Site Setting

Outcrops along SR0011 are small and poorly defined in the area of interest (Figure 1). Vertical and lateral exposure of outcrops is limited by weathered material, talus, and vegetation. A number of rock exposures on the upper slope were not measured as it was unclear whether the rock exposure was consistent with bedrock, or had been subject to movement and rotation. Outcrop measurements were made south of the railroad abutment moving southward along SR0011 in a line-mapping fashion, with five outcrops identified that were believed to represent in-place bedrock. This information was included in the rock slope stability analysis.

Field observations included identification of the structure type, rock type, hardness, dip directions, and dip values. An estimate of joint width, spacing, length, continuity roughness, and water conditions was made for each joint set measured. The presence of water reduces the shear strength along potential failure surfaces and decreases the slope stability. Three dominant types of discontinuities were identified. The discontinuities consisted of bedding planes and two sets of vertical joints.

Subsurface Boring, Sampling, and Testing

Six borings were advanced through soil using augers and standard split-spoon sampling techniques. Temporary casing was placed in the boring to facilitate geophysical logging. Within rock, borings were advanced using HQ-size core. Bedrock cores were necessary for traditional RQD values and laboratory testing. Both are used in rock-slope design. Traditional cross sections were developed showing the ground surface, top of bedrock, and cut slope information from the preliminary design.

Geophysical Logging

The main objective of borehole geophysics is to obtain more information about the subsurface than can be obtained from drilling, sampling, and testing. For this site, information was required regarding bedrock structure and discontinuities. For near-surface borehole logging, optical and acoustic televiewers may be used for this purpose. Unlike the cores recovered from the boreholes, which were sometimes incomplete, borehole geophysical logs provide a continuous *in situ* record. Log data are repeatable over long periods and comparable even when measured with different equipment.

Televiewer Logging

Televiewer logging can take the form of optical or acoustic televiewer logs. The acoustic televiewer is an ultrasonic tool requires a fluid-filled borehole to effectively evaluate borehole fractures and rugosity. Transit time and amplitude of the reflected waveform are interpreted to provide structural information about a borehole. The output of this tool commonly is presented as a virtual core.

Optical televiewer logging uses a rotating mirror to image air- or water-filled boreholes. Typical resolution is 2 mm with fracture resolution down to 0.1 mm and radial resolution to 1° depending upon borehole clarity. Data are recorded as color pixels of the borehole, which can be interpreted to provide structural information about a borehole. Interpretation of televiewer logs typically includes the location and orientation of borehole fractures.

Borehole Geophysical Data Collection

Data were collected using a Mount Sopris MGX IV portable borehole logging system. This unit uses 0.125 inch diameter steel armored single conductor cable used to raise and lower the televiewer sonde. The data were collected and managed on a personal computer using MSLog software. Data were collected with 720 measurements per turn (0.5°) around the borehole wall (horizontal resolution), at a rate of measurement every 0.3 cm (vertical resolution). MSLog provides a display and optional printout of the data as they are being collected. This information is used for field interpretation, quality control, and quality assurance.

Borehole Geophysical Data Processing and Interpretation

The borehole geophysical data were processed and interpreted using the software package WellCAD by Advanced Logic Technology (ALT). Televiewer data from each borehole were adjusted to magnetic north based upon magnetometer and accelerometer data collected with the optical data. Missing data were interpolated based on surrounding data, and resulting values normalized to establish consistent, complete information within each borehole.

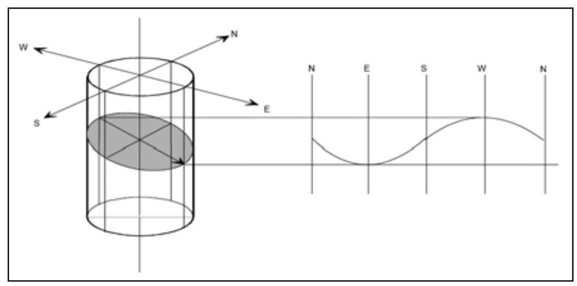

Figure 2. Fracture presentation as sine wave.

The televiewer data are presented as if the borehole wall were unfolded and flattened. North is at the extreme left side, east one quarter of the way across, south in the center, west three quarters of the way across, and north is present again on the right side (Figure 2). In this presentation, any plane not perpendicular to the borehole axis creates an elliptical shape on the borehole wall. When the ellipse is unrolled in a two-dimensional presentation with the image data, it appears as a sine wave. The radial position of the lowest point of the sine wave (the phase) indicates the azimuth of the dipping plane. Azimuth differs from strike by 90°. The amplitude of the sine wave gives the degree of tilt (or dip) for a borehole of given diameter. With an exaggerated vertical scale (1:5), the interpreter is able to identify most features of interest.

Interpretation is performed on a structure log, which the interpreter places directly over the optical televiewer log. By observing the location of borehole fractures, the operator is able to mark the observation on the structure log. WellCAD recognizes the sine wave requirements and ensures that the interpreter maintains 180° separations between the interpreted sine wave peak and the sine wave trough. Therefore, the interpreter is able to identify features that are non-planar, or when the borehole is elliptical. Under non-planar conditions, the interpretation of structural information is compromised, and the accuracy of the measured dip and azimuth is diminished. After placement, fractures were classified using the scheme shown on Figure 3. The nomenclature is consistent with conventions used to classify bedrock outcrops, and is adaped from a classification developed by Fred Paillet for subjective evaluation of permeability potential (Paillet, undated).

For all structural interpretation, the tilt (dip) is presented as the degree of vertical change from the horizontal of a plane structure. The azimuth is the direction of the tilt (dip) presented as a 360° angle

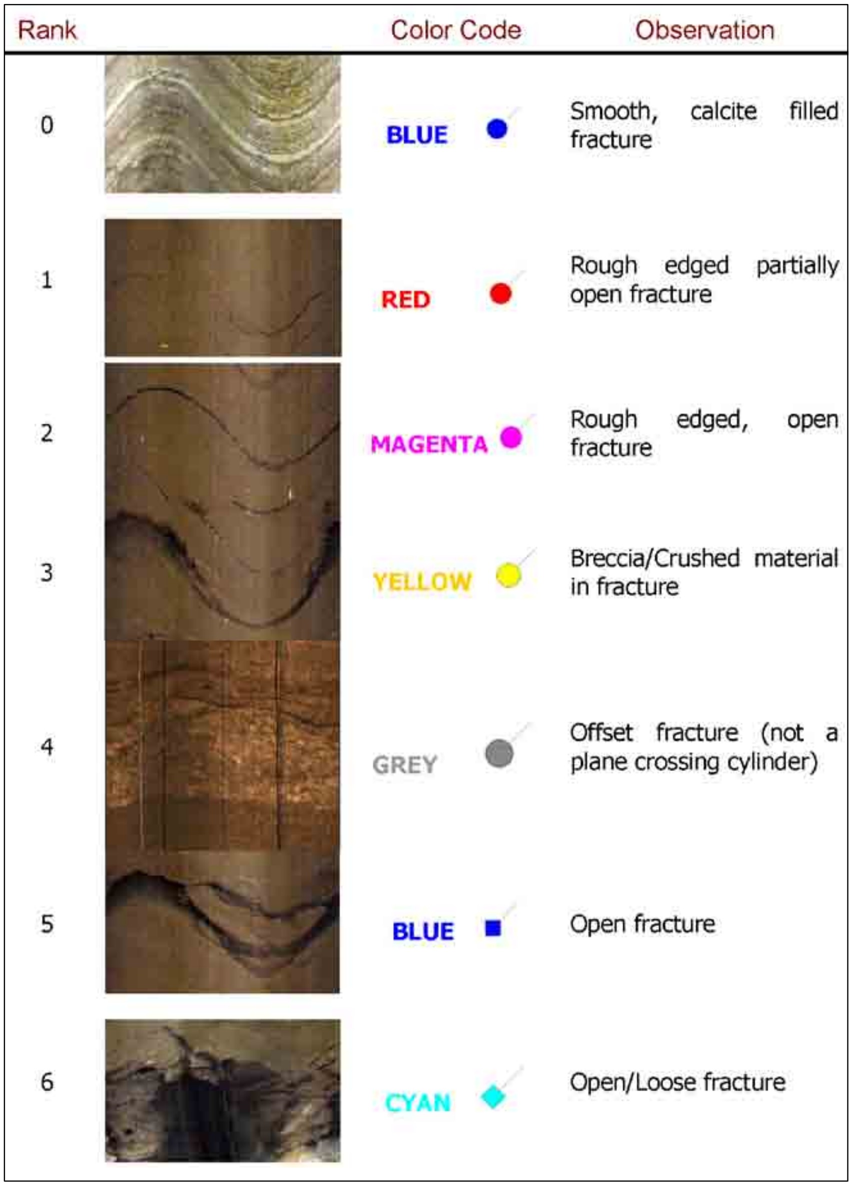

Figure 3. Fracture classification scheme.

measured from north (0° or 360°), with east being 90°, south 180° and west 270°. Strike is 90° from the azimuth for planar features. Azimuth differs from strike by 90º, but avoids the ambiguity of strike measurements, which can imply different directions.

Following interpretation, the structural data were presented as a tadpole plot. Tadpole plots represent individual features, where the tail points in the direction of dip (clockwise from the top, 0° to 359° degrees). The head of the tadpole is positioned vertically according to the median depth of the feature and positioned horizontally according to the feature tilt or dip angle, which ranges from 0° to 90° from horizontal.

As a final step, true azimuth and true dip were calculated based on the borehole inclination and azimuth data collected with the optical televiewer data. The true azimuth and dip data were used for subsequent analysis and structural (polar plot) presentations. Polar and rose plots are also used during interpretation to facilitate classification, and to monitor interpretation consistency and quality.

Vertically corrected data were imported into a spreadsheet to create tables representing the depth, azimuth, and dip and to produce histograms of fracture frequency versus depth.

Data synthesis does not differentiate between fractures, bedding planes, lineaments or other specific bedrock structural features. Any use of the term “fracture” can equally be interpreted to represent other structural features, and has only been used for convenience.

Integration into Structural Analysis

Field observations indicated that most of the rock-cut slopes are functional, but rockfalls can occur in the project area due to rain, freeze-thaw, rock fractures, wind, snow melt, springs or seeps, and differential erosion. Generally the weathering of Llewellyn Formation sandstone and conglomerate forms rubble consisting of small to medium, flat, elongate fragments to large blocky fragments.

A stereographic analysis of existing slopes was performed using RockPack III software (available from C.F. Watts & Associates) to estimate the potential for rockslides and rock falls based on the data collected in the outcrop and from geophysical logs and the existing and proposed cut-slope configurations.

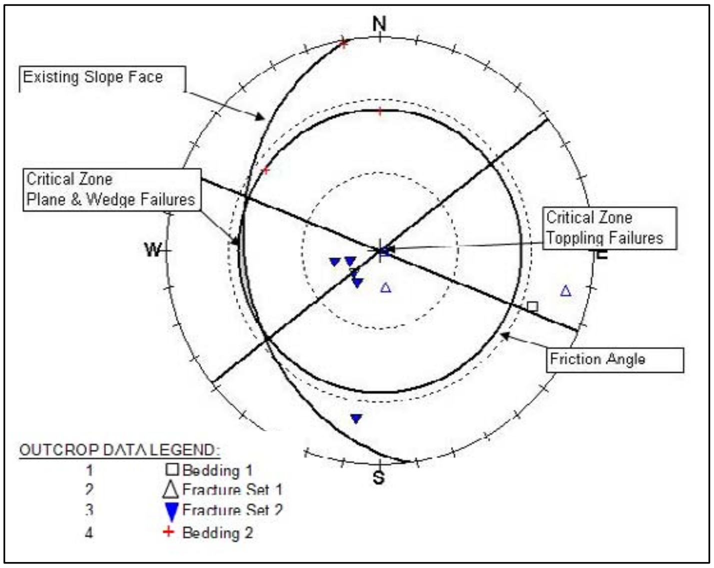

Figure 4. Rockpack III stereonet representation of Markland's Test for identification of rock slope failures using only outcrop data.

In a typical stereonet plot (Figure 4), the discontinuities falling within the shaded semicircular area indicate that there is a potential for planar failure due to bedding or joint sets. The intersection of great circles representing two groups of discontinuities within the shaded semicircular area indicates that there is a potential for wedge failure between the joint sets. The discontinuities falling within the shaded triangle region indicate potential toppling failures of the joint sets.

The introduction of the geophysical data (Figure 5) shows a stereonet plot of significantly increased detail. Biases of the geologist measuring the outcrop focused on vertical fractures. With all fractures interpreted, tabulated and imported into the RockPack analysis software, a more reliable analysis of the hillside geology emerges.

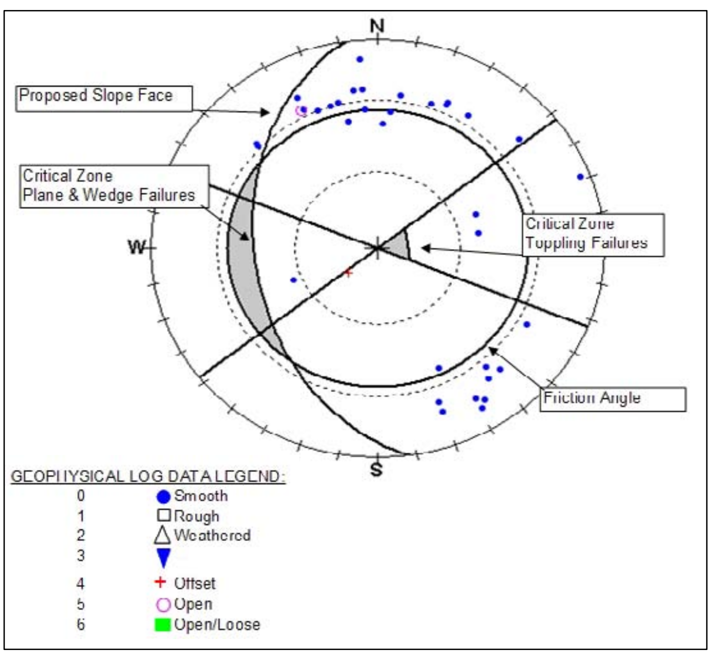

Figure 5. Rockpack III stereonet representation of Markland's Test for identification of rock slope failures using borehole geophysical data.

Effect on Project

Initial design resulted in a conservative rock slope of 2 m horizontally for every 1 m vertically (2H:1V). During rock slope analysis, geotechnical engineers were able to evaluate slopes of 1H:1V (45°), and 1H:2V (64°). Adequate borehole data were acquired in boreholes at the location of the proposed cut that enabled the engineer to recommend the steeper rock cut be constructed. The increased bedrock slope resulted in a significant reduction in construction costs and right-of-way required for the highway and slopes.

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The Magnetic Anomaly of a Lightning Strike

by Bruce W. Bevan, Geosight, 356 Waddy Drive, Weems, Virginia 22576 (geosight2@gmail.com)

Summary

Soil that has been magnetized by a lightning strike may be revealed as a magnetic anomaly that has the shape of a propeller. Paired lines of high and low anomalies may radiate from a point, and the magnetic highs may all be clockwise from the lows; alternatively, each of the lows may be clockwise from its associated high.

This type of distinctive anomaly can be found if the lightning's current flows in a horizontal direction just below the surface of the soil. A lightning strike with a vertical current will probably cause no apparent anomaly on a magnetic map; if an anomaly is visible, it may show a simple bipolar pattern that is oriented in a random direction.

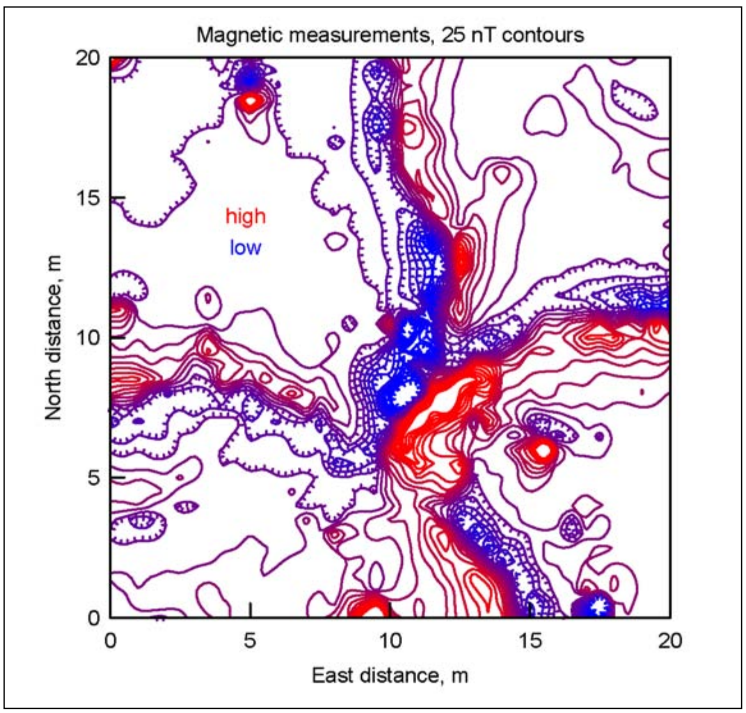

Figure 1. Total magnetic field in a 20-m square. Four radial arms are apparent in the measurements; each linear high is clockwise from a low.

Introduction

The magnetic measurements in Figure 1 reveal an anomaly that is shaped like a propeller: four linear anomalies radiate from near the middle of the area; each anomaly has a low (blue) that is counterclockwise from its companion high (red).

The measurements are approximated in the calculated map of Figure 2. The magnetization in the seven rectangular slabs (green) of the magnetic model is horizontal and is directed counterclockwise. This model suggests that it is likely that Figure 1 records the remanent magnetization of a lightning strike.

The electrical currents from a lightning strike may flow near the Earth's surface if the electrical resistivity of the soil increases with depth. The electrical current of about 30 kA (Golde, 1977, p. 318) and its associated high temperature may magnetize the soil or rock along the current's path. This remanent magnetization should have a pattern that is similar to the magnetic field created by the current flow during the lightning strike: it could be cylindrical and it should decrease with distance from the path of the current.

The Anomaly of a Cylindrical Shell

The magnetic anomaly of a cylindrical shell with a horizontal axis that is magnetized around its circumference is plotted in Figure 3. The actual anomaly of a lighting strike could be a summation of additional shells. The amplitude of the magnetic anomaly changes with the span of the cylindrical arc; Figure 3

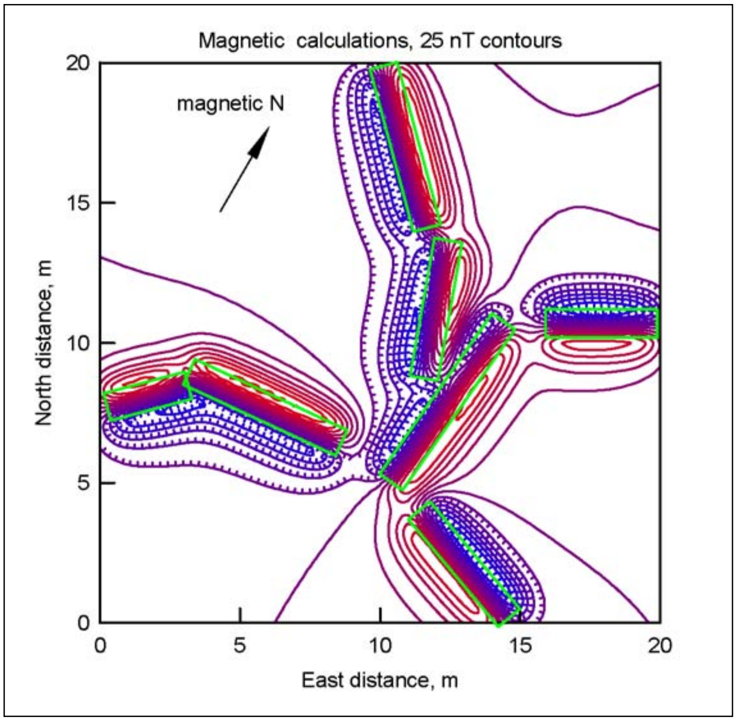

Figure 2. The calculated field of a simple magnetic model. The magnetization in each rectangular slab is horizontal and perpendicular to the length of the slab.

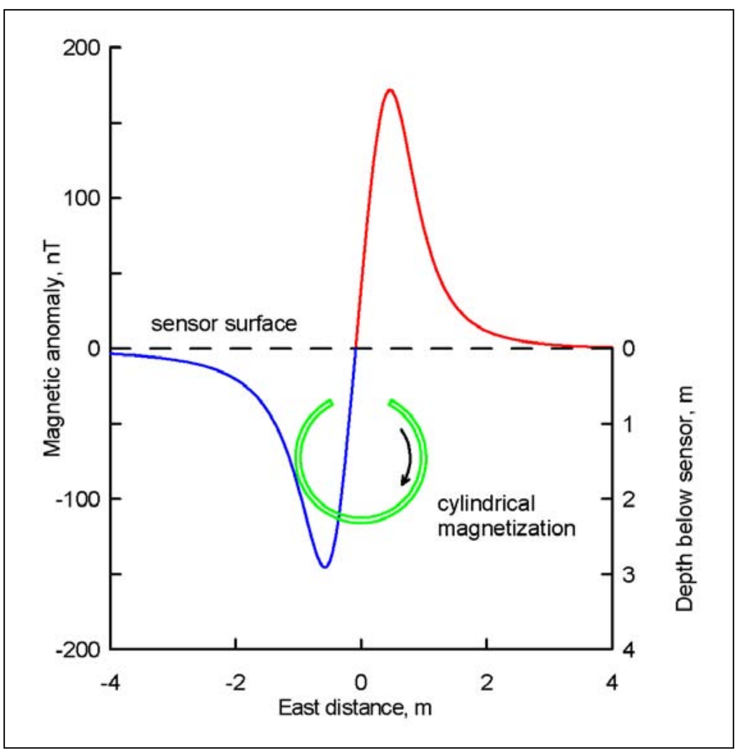

Figure 3. The magnetic anomaly of a cylindrical shell. The magnetization is cylindrical, as marked by the arrow in the cross-section of the model. Note that the upper part of the cylinder is missing.

shows a cylinder with an arc span of 304°, and this causes the greatest anomaly. If a complete cylinder is magnetized, the anomaly is zero.

The lateral currents of a lightning strike will be apparent on a magnetic map only where the upper part of the magnetized cylinder was never formed (because of a shallow current) or when the original remanent magnetization of that upper part has been randomized, perhaps by bioturbation. The inner part of the lightning path, which is most magnetic, will be undetectable because it is magnetized in a complete cylinder.

The success of the calculation in Figure 2 shows that the moderately complex model of a partial cylinder can be simplified to a horizontal slab with little loss of accuracy.

Patterns of the Anomalies

The electrical current from a lightning strike alternates in its direction during the period of that strike. The magnetic pattern in Figure 1 indicates that the primary (strongest or last) current flowed in an outward direction from near E10 N5. The four radiating arms of the anomaly may mark low-resistance paths to the current flow; in some cases these might trace the roots of a former tree. An exploration of a wider area revealed that the arms of this anomaly extend for a distance of greater than 75 m and that the amplitude of the anomaly decreased with distance from the strike point (Crew, 1990); this larger survey also revealed the magnetic anomaly of a second lightning strike.

If the electrical conductivity of the soil increases with depth, the current flow from a lightning strike may dive vertically into the soil. The anomaly of the magnetized soil from such a strike will probably be zero, for this cylinder will be magnetized around its full circumference. If a partial cylinder remains, there will be a bipolar anomaly, and this will have its greatest amplitude if half of the cylinder is present. These anomalies from partial cylinders will readily be detected but will probably be impossible to identify as lightning strikes on a magnetic map.

Maki (2005) has shown how a lighting strike may be revealed by tests of the magnetic properties of soil samples that are made in a laboratory. Soil particles that have been modified by a lightning strike may have abnormally high remanent magnetization and also Q ratios greater than ten. These laboratory tests may allow a vertical strike to be identified. Perhaps at some locations, an anomaly with an unusually high amplitude in a small area may suggest a lightning strike (Toewe and Le Van, 1966).

Other authors have given examples from the U. S. of magnetic anomalies of lighting strikes that caused radiating anomalies in Ohio and Arizona (Jones and Maki, 2005) and in North Dakota (De Vore, 2008). The patterns of five anomalies are summarized as follows: arm length 4 to more than 75 m; number of arms 2 to 6; and current direction 3 of 5 outwards. The finding at North Dakota is the only location where the resistivity stratification of the soil is known. There, the resistivity increased from 50 ohm-m at a shallow depth to 250 ohm-m at a depth of about 2 m. Some of these examples reveal an anomaly whose amplitude decreases with distance from the strike point.

It is possible that the anomaly of a lightning strike will be most apparent where the soil has a high fraction of clay or silt, for the electrical conductivity of these soils is high and many of these soils are readily magnetized. In sandy soil, such as on the coastal plain of the eastern U.S., lightning strikes appear to be detected much less frequently. This may be because the sand is less magnetizable and because the current flow would typically be vertical, since the resistivity of the soil usually decreases with increasing depth. However, fulgurites (natural hollow glass tubes formed by lightning strikes) are more likely in these sandy soils (Viemeister, 1972).

Conclusion

In a magnetic map, a lightning strike may be identified with the greatest certainty by an anomaly that has the shape of a propeller. If only a single line of paired anomalies is visible, a switch in the polarity of the anomalies along the length of the line could reveal the strike point for the lightning. A decreasing amplitude along the length of paired linear anomalies might also suggest a lightning strike. Lightning anomalies are only apparent where the cylindrical magnetization of the soil is incomplete; that is, the current path must be shallow and horizontal, or the magnetization must otherwise be eroded or fragmentary.

Appendix: Details about the Figures

Figure 1. This survey was done in northwestern Wales as part of a study of prehistoric iron furnaces at a site called Crawcwellt, which is near the town of Trawsfynydd. The magnetometer was a GEM Systems model GSM-19WG and the height of the magnetic sensor was 0.3 m. Measurement traverses were made toward the north along lines that were spaced at 0.5 m. The average spacing between measurements along each line was 0.36 m. The anomaly range is -1032 to +738 nT, and extreme highs and lows are not contoured. The Earth’s field was 49,070 nT, at an inclination of 69.7°. This survey was done in 1998 by Tatyana Smekalova (Centre for Black Sea Studies, University of Aarhus, Denmark) for Peter Crew (Snowdonia National Park Study Centre, Wales). A large-area survey was also done at this site, by John Gater and Chris Gaffney (Geophysical Surveys, Bradford). The soil is clay that contains boulders; the depth to bedrock (siltstone and sandstone) is about 7 m.

Figure 2. The magnetic model is composed of rectangular slabs with a magnetic moment per unit length of 1 Am. The slabs are 1-m wide, 0.2-m thick, and 0.45-m underground (to their tops). An algebraic summation of the anomalies from the seven slabs has been made; therefore, there will be some error near the junctions between slabs.

Figure 3. The anomaly was approximated by a ring of 77 magnetic prisms arranged at intervals of 4° around 84 per cent of a circle, and extending from 28° to 332°. The prisms were small (2 cm on a side) and 20-m long, and each had a magnetic moment of 1 Am^2. The Earth's magnetic field was the same as for Figure 1; there is little change in the anomaly if the inclination is 90°. The magnetic moment per unit of length for this model is 3.85 Am, somewhat higher than for the model in Figure 2.

Acknowledgments

The magnetic map of Figure 1 was measured by Tatyana N. Smekalova (Centre for Black Sea Studies, University of Aarhus, Denmark). The high quality of her magnetic surveys is further illustrated by her geophysical work at many other archaeological sites (Smekalova and others, 2008). This geophysical survey was done for Peter Crew (Plas Tan y Bwlch, Snowdonia National Park Study Centre, Wales). I thank Peter for adding the study of lightning strikes to his exploration of Welsh prehistory.

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Near-Surface Community News

FastTIMES *publishes contributions from societies and individuals with an interest in near-surface geophysics. Representatives of the Australian Society of Exploration Geophysicists contributed the item below. Contributions from others are always welcome.*

Publications of the Australian Society of Exploration Geophysicists Free Online to ASEG/SEG/EAGE/NSG/EEGS Members

by Michael Asten, ASEG President-Elect, and Phil Schmidt, ASEG Chairman of Publications

The ASEG is pleased to announce that all publications (***Exploration Geophysics***, ***Preview***, ASEG Conference Extended Abstracts, and Special Publications) are now available online.

A period of free access to full pdf downloads, for the year 2009, is being offered to members of the professional geophysical societies listed above.

Exploration Geophysics (a peer-reviewed journal) has a particularly strong record in mining geophysics methodology and case histories. ***Preview*** is ASEG's news magazine that reports events and latest developments in geophysics, funding sources, and industry advertising. The ASEG Conference Extended Abstracts (not peer reviewed) are a rich source of case history material and recent technical developments.

Exploration Geophysics also welcomes submissions of papers from geophysicists world-wide.

Access: use the ASEG website *www.aseg.org.au* and select Publications>Exploration Geophysics and follow the prompts.

All ASEG material is also being incorporated into the SEG Digital Cumulative Index at *http://segdl.org/journals/doc/SEGLIB-home/dci/searchDCI.jsp* (can use tick boxes at the base of the webpage) but the SEG webpage organization and tabbing of ASEG publications is still under development.

The ASEG wishes all our colleagues overseas well in 2009 and hopes the new ease of access of our publications will prove of benefit to our profession.

Coming Events

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

22nd Symposium on the Application of Geophysics to Engineering and Environmental Problems

March 29–April 2, 2009, Fort Worth, Texas

The Environmental and Engineering Geophysical Society (EEGS), general chair Doug Laymon, and technical chair Dwain Butler invite you to attend the 22nd Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) being held in the Renaissance Worthington Hotel in downtown Fort Worth, Texas. Fort Worth is a city filled with culture and western heritage and is known as the city "Where the West Begins." Fort Worth has much to offer and enjoy including the historical stockyards, great museums, exciting downtown, wonderful restaurants, and fun nightlife in Sundance Square. The SAGEEP 2009 theme is "Expanding Horizons for Near-Surface Geophysics."

We have a great technical program this year with more than 130 presentations and posters covering a wide range of subjects, including recent developments in near-surface methods, innovative uses of geophysics for challenging engineering and environmental problems, and many interesting case histories. We will also have several special sessions on topics such as **cavities and tunnels**, **agricultural geophysics**, **humanitarian water supply**, and a **special session sponsored by the NGWA**. We will also have a **student poster session**. Short courses will expose attendees to state-of-the-practice geophysical techniques and allow for the refreshing of one's skills. Course topics are **borehole geophysics**, **surface waves**, **GPR**, and **refraction tomography**.

A new feature for SAGEEP 2009 is five presentations that have been designated as **Session Keynotes**. Topics and speakers are:

- *"Odysseus Unbound: Geophysics in the Search for Homer's Ithaca" by **Greg Hodges**,*
- *"The Self-Potential Method: Did the Ugly Duckling of Environmental Geophysics Become a Beautiful Swan?" by **Andre Revil**,*
- *"The 'Nuclear Renaissance' and its Implications for Geophysics" by **Tom Dobecki**,*
- *"Robust, Broadband Finite Difference Time Domain Modeling of EM Propagation in the Subsurface" by **Jeffrey Daniels**, and*
- *"Soil Magnetism Research: State of the Art and Future Directions" by **Russell Harmon**.*

Back by popular demand for its second year are the Environmental & Engineering Geophysics University (EEGU) sessions. EEGU 2009 is a series of classroom-style sessions in which near-surface methods and their applications are presented non-technically for new students of the discipline, teachers, and managers or technical staff who are considering geophysics in an environmental or engineering investigation but wish to know more before proceeding. These sessions will be concurrent with the technical program and will be open to single- or multiple-day registrants.

This year's outdoor demonstration should be a well-attended event that will include demonstrations of state-of-the-art geophysical equipment and techniques at the historical **Fort Worth Stockyards**. The outdoor demonstrations will also be a combined event for students with social time at **Billy Bob's**, (www.billybobstexas.com), "The World's Largest Honky Tonk."

You will not want to miss the **EEGS Conference Evening**. It will be held in the historical Ashton Train Depot, instrumental in the growth of Fort Worth. It will be a wonderful night in a great atmosphere with good music, drinks, food, friends, and colleagues (http://theashtondepot.com). Be sure to attend! Also reserve yourself a spot for the EEGS Luncheon where we will hear a presentation by this year's Early Career Awardee.

We are offering two field trips. The first, on Sunday, March 29th, will consist of a guided **Segway** tour of downtown Fort Worth. The second field trip, a walking tour on Wednesday, April 1st over an extended lunch hour, will include a lecture and tour of the **Trinity River Project** (http://www.trinityrivervision.org/TRVWEB/Default.aspx). The master plan for this project addresses such issues as the environment, ecosystems, flood protection, recreational opportunities, access to the waterfront, preserving green space, and urban revitalization based around the river.

An educational technical program, social and networking opportunities, and a chance to experience the city where the west begins are just some of the reasons not to miss SAGEEP 2009! For the latest information, visit the conference web site at www.eegs.org/sageep/index.html or contact SAGEEP 2009 General Chair Doug Laymon by email at doug.laymon@tetratech.com.

International Foundation Congress & Equipment Expo '09

March 15–19, 2009, Lake Buena Vista, Florida

The annual meetings of the Geo-Institute, Pile Driving Contractors, and The International Association of Foundation Drilling are being held March 15–19, 2009 in Lake Buena Vista, Florida. Six short courses will be held on Sunday, March 15. Attendees can earn 6.5 PDHs per course. Course topics include:

- *Introduction to Instrumentation and Monitoring*
- *High Strain Dynamic Testing*
- *Estimation of Soil Properties for Foundation Design*
- *Installation and Design of ACIP Piles*
- *Managing your Safety Program*
- *Micropiles 201*

Visit www.ifcee09.org for more information.

34th Southwest Geotechnical Engineers Conference

34th Southwest Geotechnical Engineers Conference

Event Announcement
Phoenix, Arizona
May 11 - 14, 2009

Hosted by the
Arizona Department of Transportation & Federal Highway Administration

Preliminary Agenda:

Monday, May 11	5:00 pm to 8:00 pm	Registration/Reception/Exhibits
Tuesday, May 12	8:00 am to 5:00 pm	Technical Sessions/Exhibits
Wednesday, May 13	8:00 am to 5:00 pm	Technical Sessions/Field trip/Exhibits
Thursday, May 14	8:00 am to 12:00 pm	Technical Sessions

Wednesday, May 13 will be specifically used to demonstrate the practical application of geophysical methods for geotechnical subsurface investigations. Due to the limited time frame of the conference, the technology demonstration will be limited to seismic refraction and resistivity techniques. The following rough agenda is envisioned for that day:

- 2 or 3 state DOT case histories;
- Field trip to demonstrate equipment supplied by the various manufacturers;
- Presentation of data reduction and interpretation using the current state of practice;
- Presentation of state of the art seismic equipment and processing.

Conference Location: Crowne Plaza Hotel, Phoenix
2532, W. Peoria Avenue
Phoenix, AZ., 85029
Phone: (602) 943-2341; (800) 972-3574
Fax: (602) 331-9351

Block of Rooms: A block of rooms at the Crowne Plaza Hotel has been reserved at a rate of $96.00 per night, plus tax, under the Southwest Geotechnical Engineers Conference. Reservations should be made no later than April 17, 2009. Please identify yourself as an attendee of the 2009 Southwest Geotechnical Engineers Conference when making your reservations. Early reservation is strongly recommended. Hotel check-in time is 3:00pm and check-out time is 12:00 noon.

Registration Fee: **$150.00** which includes a reception on Monday evening, and breakfast, breaks and lunch on Tuesday, Wednesday and Thursday.

Travel to/from Airport: Both shuttle and taxi services are available. Shuttle charge is $23.00, one-way (www.supershuttle.com); Taxi charge is $45.00, one-way. Please contact the persons listed below, or visit the hotel website (link above), for more information on these services.

Planning Information:

Norman Wetz	Daniel Alzamora
Arizona DOT	FHWA
(602) 712-8093; (602) 526-4099	(720) 963-3214; (303) 594-5210
Email: nwetz@azdot.gov	Email: Daniel.alzamora@fhwa.dot.gov

Registration for the Conference will be through the Arizona Technical Training Institute (ATTI)

Call for Papers: Near Surface 2009

The 15th European Meeting of Environmental and Engineering Geophysics is being organized by the Near Surface Geoscience Division of the EAGE for September 7–9, 2009 in Dublin, Ireland. Program information and proposed topics for which you are invited to contribute abstracts are available on the EAGE website at www.eage.org.

Call for Papers: The 9th SEG Japan Symposium

October 12–14, 2009, Sapporo, Japan

Abstracts due March 31

The Society of Exploration Geophysicists of Japan (SEGJ) announces a Call for Papers for the 9th SEGJ International Symposium on Imaging and Interpretation – Science and Technology for Sustainable Development, which will be held at Hokkaido University Conference Hall, Sapporo, Japan on October 12-14, 2009. The symposium will be co-sponsored by ASEG, EAGE, EEGS, KSEG, SEG and VAG. Electronic submission of short abstracts by March 31 is strongly encouraged.

About Sapporo

Sapporo is the capital city of Hokkaido, the northernmost prefecture of Japan. Hokkaido is a popular tourist destination, renowned for its wildlife (foxes, deer, bears, salmon), hot springs, volcanoes, seafood, and farm products. The G8 Summit took place in Hokkaido in July 2008. Sapporo itself has much to offer the visitor: wonderful Japanese restaurants, world-class shopping, an historic fish market, noodle shops and a beer museum, as well as providing convenient access to the other tourist areas of Hokkaido. October is the best season for tourism and scientific activity.

Symposium Theme

The theme of the symposium is "Imaging and Interpretation – Science and Technology for Sustainable Development." Sustainable development strives to balance our need for resources extracted from the Earth with the preservation of the environment for future generations. Geophysical exploration has been indispensable as a means of locating and delineating natural resources. There is now increasing awareness, however, that geophysics can contribute to the sustainability of the environmental, social and human systems in small and large scales. The symposium will cover theoretical developments, laboratory and case studies related to this theme, as indicated by the number and range of proposed sessions. Please visit our website (www.segj.org/is/9th/) for more information.

Recent Events

***FastTIMES** presents contributed summaries of recent events to inform readers who were unable to attend. As a service to others, please send the editors summaries of events you attend for possible inclusion in future issues.*

AGU Near Surface Geophysics Focus Group Activities at the Fall AGU Meeting, December 2008, San Francisco, California

by Lee Slater, Earth & Environmental Sciences, Rutgers University, Newark, New Jersey (lslater@andromeda.rutgers.edu)

The American Geophysical Union (AGU) Near Surface (NS) Geophysics Focus Group convened six special sessions at the 2008 Fall AGU Meeting, with over 100 abstracts submitted. The special sessions, which focused on a range of topics of relevance to the broad AGU community, included stratigraphic applications of geophysics, joint inversion methods for assessing natural resources, geophysical imaging of flow in dual porosity media, monitoring techniques for coupled thermo-hydro-mechanical processes, and the use of geoscientific data in revitalizing Afghanistan. The NS Focus Group also co-sponsored the popular Hydrogeophysics special sessions organized by the Hydrogeophysics Committee of the Hydrology Section.

The NS Executive Committee meeting was attended by the Environmental and Engineering Geophysical Society (EEGS) President Jon Nyquist and Inter-societal liaisons officer Bruce Smith. Plans for improving NS-EEGS collaborations were discussed, in addition to collaborations with other near-surface geophysics communities, including the Society of Exploration Geophysicist Near Surface Geophysics Section (SEG NSGS).

The NS focus group hosted its annual luncheon, which was attended by 65 NS members. It was an opportunity to visit with friends and colleagues and get an update on the activities of the focus group. Lee Slater (Chair) acknowledged Rosemary Knight (Past Chair) for her tireless contributions to the focus group and the near-surface geophysics community. He then gave an overview of the current state of the focus group (596 primary members; 1939 secondary members; 2535 members in total) and encouraged the involvement of members for the continued success of AGU NS by proposing special sessions for the AGU meetings, and volunteering for officer positions in the focus group. Elliot Grunewald (student representative) talked about his new role in organizing the student members and helping NS serve the interests of its student body. Rosemary Knight introduced a new session format “Back to Basics” that will be implemented at the 2009 Joint Assembly in Toronto.

Louise Pellerin (Vice-Chair) talked about the broader near-surface geophysical community, the various aspects of the general community that is served by each society, and inter-society relations (AGU-NS, EAGE NSGD, EEGS, SEG NSGS). She also launched the design competition for an NS logo that aims to capture the diverse methods and applications of near-surface geophysics.

The NS focus group launched an initiative to enhance the participation of students in focus group activities, headed Elliot Grunewald (Stanford University), the first student representative. NS sponsored a casual student luncheon led by Elliot and attended by 14 students from 8 universities.

Brainstorming at the luncheon was productive and demonstrated that students are eager to play an active role in the NS group. A student webpage will allow information relevant to students to be easily accessed and posted. In addition to job listings and graduate program opportunities, this webpage will advertise broader opportunities including fieldwork experience, grants and funding, session organization/co-chairing, professional development, and social gatherings at future meetings.

The focus group was active in the AGU-hosted second family science event. The "Exploration Station" was held on Sunday, December 14 from 12 to 4 p.m. and was organized with the help of Rochester Institute of Technology (RIT) and NASA Solar Dynamics Observatory's Education and Public Outreach department.

The NS Focus Group was well represented by Andrew Parsekian (PhD student, Rutgers-Newark) who had two demonstrations on display: (1) a mock "leaky landfill" showing how electrical resistivity methods can be used to detect and monitor leaks from landfill liners, and (2) exploration with induced polarization showing how the IP effect manifested as voltage decay curves can be used to detect ore bodies. The University of Kansas Center for Remote Sensing of Ice Sheets (CReSIS) had an exhibit on the study of polar ice sheets and their contribution to sea level change, and a demonstration of ice flow processes. The Exploration Station included a scavenger hunt encouraging children to visit the various demonstrations and participate in each activity. The event was attended by approximately 150 members of the public and is likely to be repeated at future meetings.

Call for Nominations for the 2010 Bower Award and Prize for Achievement in Science

by Dennis M. Wint, President and Chief Executive Officer, The Franklin Institute, 222 N. 20th Street, Philadelphia, Pennsylvania 19103

On behalf of The Franklin Institute, I invite you to nominate candidates for the 2010 Bower Award and Prize for Achievement in Science. This award is presented annually by The Franklin Institute to an individual of any nationality for outstanding work in the basic, applied, or engineering sciences. Each year, a predetermined field of study is chosen as a theme. A gold medal and a cash prize of $250,000 are awarded to the individual selected to receive the award.

The theme for the 2010 Bower Award and Prize for Achievement in Science is Earth Systems. The Franklin Institute seeks nominations of individuals who have made significant scientific contributions to our understanding of the interrelationships among Earth Systems leading to increased predictability of natural or human-induced changes on the planet. Nominations should recognize efforts that encompass various earth systems and processes, including: the Earth's interior, lithosphere, hydrosphere, biosphere, and atmosphere, biogeochemical cycles, and Earth history.

The Franklin Institute Awards Program is among the oldest and most comprehensive international science and technology awards programs in the world. The list of Franklin Institute laureates reads like a “Who's Who” in the history of 19th, 20th, and 21st century science, including such titans as Thomas Edison, Marie and Pierre Curie, Rudolph Diesel, Albert Einstein, Nikola Tesla, Enrico Fermi, Ruth Patrick, Stephen Hawking, Ralph Cicerone, Sir Martin Rees, Noam Chomsky, Paul Baran, Rob Van der Voo, Luna Leopold and M. Gordon Wolman, and Wallace Broecker. I urge you to nominate a candidate whose name should be added to this distinguished list.

For more information on nominating a candidate for The 2010 Bower Award and Prize for Achievement in Science, please visit: www.fi.edu/franklinawards/call.html.

Please forward this call for nominations to colleagues who might wish to make a nomination or to professional associations to which you belong. Please also feel free to post this material on any appropriate websites you may manage.

Questions about the appropriateness of a particular nomination are welcome and should be directed to Dr. Frederic Bertley, Vice President, The Franklin Institute, at fbertley@fi.edu. If you know of a candidate who has made an extraordinary contribution in the area of Earth Systems, I strongly encourage you to participate in this 2010 Bower nomination process. **The deadline for nominations is April 30, 2009.**

Call for Articles on Hydrogeophysics for The Leading Edge

by Richard D. Miller, Editorial Board member, ***The Leading Edge*** (rmiller@kgs.ku.edu)

The October 2009 issue of SEG's The Leading Edge (TLE) will showcase articles on hydrogeophysics. Each month TLE features a special section highlighting research and case studies on important, current topics that are of interest to a broad audience of geophysicists. With a circulation of over 30,000, TLE is an excellent way for hydrogeophyiscs authors to exposure their work the exploration geophysics community. Articles for consideration will be accepted until June 15. For more information contact Rick Miller (rmiller@kgs.ku.edu) or the editorial calendar page of TLE.

SAGE 2009: Attention Students!

Deadline for Application: March 27, 2009

www.sage.lanl.gov

The Summer of Applied Geophysical Experience (SAGE) is a unique educational program designed to introduce students in geophysics and related fields to "hands on" geophysical exploration and research. The program emphasizes both teaching of field methods and research related to a variety of basic and applied problems.

SAGE...

- teaches modern geophysical exploration techniques: seismic reflection and refraction, gravity and magnetics, electromagnetics (including magnetotellurics), and electrical resistivity
- involves extensive hands-on field experience
- integrates geophysical methods to solve real geological problems
- addresses geological problems of research and practical interest
- utilizes multi-institutional resources and expertise
- includes classroom instruction and supporting lectures by academic and industrial professionals
- incorporates computer processing and modeling
- provides experience in data synthesis and report preparation
- open to undergraduate and graduate students
- open to U.S. and foreign participants
- sponsored by the Los Alamos National Laboratory branch of the Institute of Geophysics and Planetary Physics, University of California
- supported by the U. S. Department of Energy, the U. S. National Science Foundation, the U. S. Geologic Survey, the Society of Exploration Geophysicist, a consortium of large and small companies, and student fees
- June 15 - July 11, 2009, based in Santa Fe, New Mexico, USA

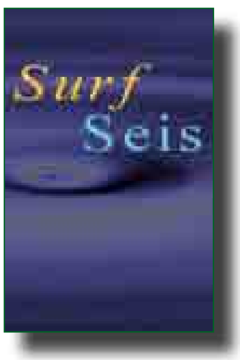
Industry Corner

FastTIMES *accepts timely and relevant news items from companies as well as brief company profiles. Send your submissions to the editors for possible inclusion in the next issue.*

EGA Listed as One of Houston's Largest Environmental Companies

Environmental Geophysics Associates (EGA) has been listed in the Houston Business Journal as one of the "Largest Environmental Companies" in 2008 in the Houston area, Texas.

EGA was founded in 1994 to provide environmental, engineering, and shallow oil and gas geophysical services. EGA provides a complete range of geophysical services to a diverse list of clients throughout the United Stades and overseas. For more information, visit www.environgeophysics.com.



KGS Announces Impending Release of SurfSeis 3.0

New features in SurfSeis 3.0 software not in version 2 include: utilization of higher modes of the Rayleigh wave, inversion using *a priori* density information, friendlier dialogs, new menus complementing the existing interface, known bugs removed, and improved compatibility with all existing and future KGS seismic software (WinSeis, SeisUtility, SeisTomo, SeisModel, and others).

For more information visit our website at www.kgs.ku.edu/software/surfseis/index.html or call Mary at (785) 864-2176.

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Environmental and Engineering Geophysical Society

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*Payments are not tax deductible as charitable contributions although they may be deductible as a business expense. Consult your tax advisor.

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