4:00

4pMU7. The acoustics of a symmetric free reed coupled to a pipe resonator. James P. Cottingham (Phys. Dept., Coe College, Cedar Rapids, IA 52402)

The Asian free-reed mouth organs employ symmetric free reeds mounted in resonating pipes, with the reed vibration strongly coupled to the pipe resonance. The sheng, the sho, and the khaen use a single pipe for each reed, constructed so that the pipe resonance frequency is fairly close to the natural frequency of the reed. The playing frequency is typically slightly above the resonant frequencies of both the reed and the pipe. The free-reed pipe with finger holes (known in China as the bawu) employs a pipe resonator of variable effective length in which both the pipe resonance and sounding frequency are normally well above the natural reed frequency, resulting in a striking change in tone quality. The operation of these instruments has been studied both experimentally and theoretically, with particular attention to the coupling of the reed vibration with the pipe resonator. Experimental measurements include both studies of reed vibration and impedance measurements of the pipes. In general, the experimental results can be shown to agree with the predictions of simple theoretical models.

4:15

4pMU8. The influence of upstream geometry on the activation pressure of free and restricted reed configurations. Marius O. Vermeulen, Jabus A. Wessels (Dept. of Medical Physiol., P.O. Box 19063, Tygerberg, 7505, Cape Town, South Africa, jaw@gerga.sun.ac.za), and Theodore W. von Backstrm (Univ. of Stellenbosch, Matieland, South Africa)

This paper describes a computationally efficient algorithm for the automatic calculation of reed activation pressure. The method was evaluated using both free and restricted reed configurations which were not connected to any external air column. It is shown how the reed activation is influenced by intrinsic factors such as rounded and minute burrs on the edge of the reed as well as extrinsic factors such as upstream geometry of the experimental apparatus. The introduction of constrictions in the flow path upstream from the reed resulted in marked changes in the activation pressure which was highly dependent on the length of the constriction. Expansions of the same magnitude, however, had less influence on the reed activation pressure.

4:30

4pMU9. A complexity measure for musical scales. Alpar Sevgen (Dept. of Phys., Boğaziçi Univ., Bebek 80815, Istanbul, Turkey, sevgena@boun.edu.tr)

Equally tempered scales with N semitones and M notes and interval structures $\mathbf{n}=\{n_1,n_2,\ldots,n_M\}$, where n_k is the number of semitones between the notes t_k and t_{k+1}, possess the following properties: Each distinct interval structure **n** corresponds to a multiplet of N scales. Members of a multiplet can be labeled by a set of integers $\{c\}$, modulo N, called scale labels. Each scale label is the *difference* between the number of sharps and flats occurring in that scale and is unique within the multiplet if N and M are relative primes. This labeling does not differentiate between different scale structures.To do this, *complexity* is introduced as the *sum* of the number of sharps and flats occurring in a scale. For $N=12$ and $M=7$, out of 462 possible scale structures, the major scale and its cyclical permutations, called modes, have the minimum complexity which allows the practical use of the key signatures in music. Complementary scales where notes and no notes are interchanged have the same complexity. The minimum and maximum complexity scales occupy the opposite ends of the energy spectrum under the force laws $\pm\, n^{\alpha}$ $(\alpha\neq 0)$, between the notes of a scale.

FRIDAY AFTERNOON, 2 JUNE 2000 SPANISH ROOM, 1:30 TO 5:15 P.M.

Session 4pPA

Physical Acoustics: Outdoor Sound Propagation and Acoustic Seismic Coupling

Gregg D. Larson, Chair

School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332

Contributed Papers

1:30

4pPA1. Systematic investigation on acoustic-to-seismic responses of landmines buried in soil. James M. Sabatier and Ning Xiang (Natl. Ctr. for Physical Acoust., Coliseum Dr., Univ. of Mississippi, University, MS 38677, sabatier@olemiss.edu)

Recently, acoustic-to-seismic coupling has been successfully applied to landmine detection [Sabatier and Xiang, J. Acoust. Soc. Am. **105**, 1383 (1999); **106**, 2143 (1999)]. When airborne sound penetrates the surface of ground it is refracted towards the normal. If a landmine is buried below the surface of an insonified patch, the transmitted waves will be scattered or reflected, resulting in increased ground surface vibrational amplitudes. These distinct acoustic-to-seismic coupled vibrational changes are sensed using a scanning laser Doppler-vibrometer (LDV) device. To better understand this mine detection phenomenon, the present work is a systematic investigation of the acoustic-to-seismic response to different types of mines in different soil types and at different burial depth has been conducted. [This work is supported by U.S. Army Communications-Electronics Command.]

1:45

4pPA2. Air acoustic sensing of seismic waves. Gregg D. Larson, James S. Martin (School of Mech. Eng., Georgia Inst. of Technol., Atlanta, GA 30332-0405), Waymond R. Scott, Jr., and Cheng Jia (Georgia Inst. of Technol., Atlanta, GA 30332)

Propagation of elastic waves in damp, compacted sand involves pressure, shear, and Rayleigh waves. The associated seismic surface displacements can be detected by sensing the acoustic pressure immediately above the surface. Propagation speeds are very low in sand. The high wave numbers of seismic displacements are, therefore, evanescent in air. Thus, the acoustic pressure can only be measured well within a seismic wavelength of the surface. Planar near-field acoustic holography techniques can then be used to back-propagate these signals and calculate surface displacements. Measurements have been made using a laboratory experimental model to investigate the potential of using this technique to detect buried land mines. The experimental model utilizes a surface-coupled transducer to generate elastic waves in a sand-filled tank, which simulates the earth. The microphone and a radar system were used to independently

measure the surface displacements. Data taken with both sensors compare well and exhibit the signature of a buried inert antipersonnel mine. For a 100–800-Hz incident pulse, the mine signature can be seen in the raw microphone data when the height of the microphone is less than 3 cm. Holographic signal-processing techniques will be investigated to increase the allowable height for the microphone. [Work supported by ARO.]

2:00

4pPA3. Electric arc source for high-frequency seismic measurement.
James S. Martin, Gregg D. Larson, Peter H. Rogers (School of Mech. Eng., Georgia Inst. of Technol., Atlanta, GA 30332-0405, james.martin@me.gatech.edu), and Waymond R. Scott, Jr. (Georgia Inst. of Technol., Atlanta, GA 30332-0250)

An electric arc source was designed to study high-frequency seismic surface wave propagation. The noncontact nature of this source made it feasible for use in synthetic aperture transmit arrays. The transmit signal, which was not linearly controllable, was found to be predominantly in the 1- to 4-kHz band with a Gaussian spectrum. This is an octave below the simultaneously generated air acoustic pulse. The source was used to create a synthetic line array in conjunction with a stationary receiver. The experiment was conducted in a sand-filled tank. Surface wave speeds in the range of 80 m/s were measured on the resulting seismograms. Significant dispersion occurred in the propagating waveform at distances both near and far from the source. Surface wave arrivals were discernable over 1 m from the source and compressional head waves could be observed within 30 cm. The data were in good agreement with lower frequency measurements made by other techniques. The surface wave generation was studied and found to be a combination of the surface interaction of the arc and the air acoustic interaction. Strong hysteresis was observed in the first arcing event. Later, the signal was smaller but sufficiently stable for averaging. [Work supported by ARO.]

2:15

4pPA4. Seismic/electromagnetic system for landmine detection.
Waymond R. Scott, Jr. (School of Elec. and Computer Eng., Georgia Inst. of Technol., Atlanta, GA 30332-0250), Gregg D. Larson, James S. Martin, and Peter H. Rogers (Georgia Inst. of Technol., Atlanta, GA 30332-0405)

A system has been designed for the detection of buried landmines. The system uses a stationary seismic source in conjunction with a movable displacement sensor that is based on an 8 GHz CW radar. The sensor measures the surface displacement by analog demodulation of the radar signal, which is reflected from the soil surface and modulated by the surface motion. The sensor is not in direct contact with the soil surface and is, therefore, capable of interrogating surface motion immediately above a buried mine. This configuration provides the dual advantage of removing half the seismic propagation path that would be encountered with a classical pulsed echo technique and detecting localized fields that would not propagate to a remote receiver. The system has been used in the laboratory to image inert antipersonnel mines and simulated antitank mines buried in damp compacted sand. Signal processing in the wave number domain provides significant improvement in the contrast between mine-related and background motion. The simplest detection cue for antipersonnel mines was found to be low-frequency resonances of their trigger mechanisms. These responded to seismic excitations with substantial local displacement. The resonances made these mines easily discernable from buried clutter such as rocks and sticks. [Work supported by ARO.]

2:30

4pPA5. A three-dimensional model for elastic waves in the ground.
Christoph T. Schroeder, Kangwook Kim, and Waymond R. Scott, Jr. (School of Elec. and Computer Eng., Georgia Inst. of Technol., 777 Atlantic Dr., Atlanta, GA 30332, christoph.schroeder@ee.gatech.edu)

A three-dimensional finite-difference time-domain model for elastic waves in the ground has been developed and implemented on a massively parallel computer. The model is based on the three-dimensional equation of motion and the stress–strain relation, from which a first-order stress-velocity formulation is obtained. The boundary between the soil and the air is modeled as a free surface. A perfectly matched layer is implemented at the remaining grid edges to absorb the outward traveling waves. The numerical model has been developed as part of a project in which elastic and electromagnetic waves are used synergistically to detect buried landmines. The numerical model is being used to study the interaction of the elastic waves with the buried mines. To verify that the model accurately predicts the mine–wave interaction, the eigenfrequencies of various solid bars and plates are determined numerically and compared to analytical solutions. Currently, the model is being refined to incorporate loss within the bulk medium. Results will be shown for various landmines buried in both loss-free and lossy ground. [Work supported by ARO and ONR.]

2:45

4pPA6. Detection of land mines in fluid-saturated unconsolidated soil: Numerical modeling.
Yanqing Zeng and Qinghuo Liu (Dept. of Elec. and Comput. Eng., Duke Univ., Durham, NC 27708)

Because of the strong interactions of waves with the solid grains and the fluid in the pore space, it is more appropriate to model the soil as a fluid-saturated unconsolidated material than a single-phase elastic medium. A three-dimensional finite-difference method for modeling acoustic waves propagating in fluid-saturated unconsolidated soil has been developed. Instead of the conventional elastic wave equations, Biot's equations are used for the poroelastic model. Based on the strain–stress relationship, Biot's equations are reformulated into a first-order hyperbolic system which is equivalent to strain-velocity formulation. A perfectly matched layer (PML) is used to absorb outgoing waves at the truncated boundary of an unbounded medium. The numerical method is validated by comparing numerical results to an analytical solution. Models of a land mine buried in fluid-saturated unconsolidated soil are developed. The numerical method is used to study the interaction of acoustic waves with the buried mines. Comparison of these results is made with those for a buried land mine in a conventional single-phase elastic soil model.

3:00–3:15 Break

3:15

4pPA7. Acoustically induced slow dynamics in nonlinear mesoscopic elastic materials.
Alexander M. Sutin (Stevens Inst. of Technol., 711 Hudson St., Hoboken, NJ 07030), Paul A. Johnson, and James A. TenCate (Los Alamos Natl. Lab., Los Alamos, NM 87545)

We have known about slow dynamics in rock due to continuous wave excitation drive for several years (http://www.ees4.lanl.gov/nonlinear). TenCate, Smith, and Guyer (see abstract, this meeting) have recently discovered that both the elastic modulus and the wave dissipation display log time recovery in granular solids, and that it may be thermally or mechanically induced. Much to our surprise, we have discovered that a CW or broad-frequency band acoustic source can also induce slow dynamical response. This response was observed as a variation of the ultrasonic probe wave amplitude, the resonance frequency, and Q factor after the action of a pump wave. The slow time recovery took place in materials such as powdered metals, damaged materials, concrete, and rocks as well. The variations of material properties due to the action of pump waves lead to transient amplification and an obscuration of CW probe waves. The observed behavior may be more universal than was first thought. The results have potential implications to many topics, including laboratory wave studies, earthquake strong ground motion, elastic waves emanating from a point source, damage detection, and manufacturing processes. [Work supported by Stevens and by the Department of Energy: Office of Basic Energy Sciences.]