Introduction to this special section: Nonreflection seismic and inversion of surface waves and guided waves

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Seismic imaging need not be synonymous with or rely on the presence of reflectors in the Earth. Much can be gleaned from the nonreflected wavefield. For example, direct waves map out smooth velocity variations in crosswell seismic tomography, wide-angle refracted waves play a crucial role in full waveform inversion (Hole et al., 2005), and surface waves provide unmatched sensitivity to near-surface shear-wave velocity structure. Guided waves exist in both cracks (Korneev, 2008) and boreholes, the latter referred to as tube waves. The famous Biot slow wave is itself a guided-wave phenomenon akin to a tube wave (Norris, 1987). Surface-wave dispersion has a long history in seismology and was the first seismic characteristic to be subjected to an automated inversion procedure (Dorman and Ewing, 1962).

Surveys based on surface waves provide a low-cost, noninvasive means of probing the shallow subsurface using either active sources (Xia et al., 1999) or in passive mode using microtremors (Aki, 1957, 1965; Louie, 2001; Okada, 2003). In fact, the past decade has witnessed a revival in the microtremor method because of the realization that ambient noise correlations are closely related to the surface-wave Green's function (Campillo and Paul, 2003). Recent work has shown that other surface-wave observables besides dispersion possess sensitivity to density in addition to shear-wave velocity (Lin, et al., 2012). When velocity decreases with depth, the existence of leaky waves (Ryden and Park, 2004) attests to the richness of nonreflected-wave phenomena. In a way, it is too bad that these topics must be collectively identified by what they are not (i.e., nonreflection); however, the negative terminology emphasizes the gaping hole in our understanding of the subsurface if only reflections are taken into account.

It is with this background that the special section has come together. Surface waves feature prominently in many of the outstanding articles that follow. Guided, leaky, and refracted waves round out the cast of seismic wave types that appear in this special section. The articles are grouped into four subsections:

1) Surface waves—active and passive
2) Surface waves—industry data applications
3) Surface waves—case histories
4) Refracted waves and instrumentation

Leading off the subsection on active and passive surface waves, Xia et al. give an overview of the multichannel analysis of surface waves (MASW) and its extension to Love waves. Because of their complete insensitivity to P-wave velocity, Love waves, in comparison to Rayleigh waves, have simpler dispersion curves with a more stable inversion. Xia et al. further discuss the amplitude of Love waves and the inversion for Q profiles from active-source data. Next, Hayashi et al. determine S-wave velocity structure to depths of 2–3 km at sites within the Los Angeles Basin using two-station microtremor array measurements (2ST-MAM). Hayashi et al. compare their method to MASW, borehole velocity logs, and a community velocity model for Southern California. In the third article of the section, Behm and Snieder show that Love waves offer the possibility of further reducing the inherent ambiguity in surface-wave imaging compared to the more commonly used Rayleigh waves. From a continuous broadband data set of more than 50 stations that recorded traffic noise, Behm and Snieder were able to measure Love-wave dispersion and relate its spatial variation to the local geology. The authors comment on the unexpectedly high signal-to-noise ratio of the traffic-induced Love waves over the frequency band of 1.5–5 Hz. This observation is in harmony with that reported in the earlier article by Xia et al. for Love waves. The subsection ends with an article by Xu et al. that discusses the application of seismic interferometry to surface-wave imaging. Close attention is paid by Xu et al. to the effects of station density and spread length on dispersion-curve resolution with passive techniques. The authors are able to detect two low-velocity zones near a tunnel on the Yangtze River that they interpret as potential landslide planes.

The subsection on industry applications includes articles by Boiero et al. and Douma and Haney. Boiero et al. demonstrate remarkable success fusing leaky waves into the surface-wave inversion problem. The authors show definitively that subsurface velocity information accurately obtained from guided P- and S-waves can be jointly inverted with S-wave velocity information estimated from Rayleigh or Scholte waves. Boiero et al. compare their results to acoustic full waveform inversion and point out that the enhanced near-surface models computed from joint inversion of surface and guided waves can provide better shallow starting models for full waveform inversion. In a study of the nonlinearity inherent to dispersion curve inversion, Douma and Haney present a method designed to quantify the nonuniqueness of acceptable subsurface models. The authors compare linearized surface-wave dispersion-curve inversion initialized with different starting models to the results of a nonlinear search. Douma and Haney make the point that, for bandlimited data, the highest frequencies define a shallow unresolved region in the subsurface in a similar way to how the lowest-frequencies determine the maximum depth of resolution.

Case histories form the theme of the third subsection. The utility of MASW to a broad array of problems in civil engineering is demonstrated in Park's article by novel approaches to site characterization. Park highlights applications targeting quantification of a ground-shaking hazard, foundation properties of a proposed nuclear plant site, and improving the understanding of highway stability. Park describes the advantages of combining active and passive surveys to sense shallow and deep structure in South Africa. A second article in this special section with Boiero as lead author describes two field cases from Scandinavia concerning water resource mapping and site characterization for tunnel construction. Boiero et al. analyze surface-wave dispersion curves with a Monte Carlo inversion technique and in the process address the nonuniqueness problem, thereby avoiding falling into local minima of the misfit function. Comparisons of the surface-wave profiles are made to borehole data and the results of seismic reflection surveying. Several case studies by Suto describe MASW surveys at landfill sites in Australia where objectives include precise delineation of the base of a landfill, monitoring of compaction, characterization of an incipient sinkhole, and gauging ground strength in lieu of a large commercial development. Suto discusses a study in which disagreement exists between results from MASW data and dynamic cone penetration tests. In closing, the author speculates as to why shear-wave velocity analysis of the near surface is yet to be embraced by geotechnical engineers.

Articles in the final grouping push the state-of-the-art in near-surface refraction imaging and instrumentation. Palmer discusses the generalized reciprocal method of refraction imaging and adaptations of the method to work with common-offset gathers (COG). The adaptations offer benefits in the form of convenient determination of the crossover distance and improved resolution at the base of the weathering zone, in particular for low-angle thrust faults. An advantage of the COG adaptations lies in their ability to rapidly assess large volumes of refraction data. Ivanov et al. present a study on the joint analysis of refractions with surface waves, or JARS method. In contrast to conventional refraction tomography, the JARS method addresses the inherent nonuniqueness of the inverse refraction problem by defining an initial V_s model based on MASW. Ivanov et al. describe several field applications of the method, including one from a levee in southern New Mexico where a velocity inversion is resolved at 10-m depth. Daley et al. give an account of field testing of a fiber optic cable for seismic applications. The fiber optic cable is an exciting new development in near-surface instrumentation with the potential to provide nearly continuous sampling in space, in contrast to traditional point sensors. Daley et al. conduct tests at sites in Alabama, Australia, and Germany in both surface and borehole environments where high-amplitude ground roll was observed; as result, the authors speculate that fiber optic cables may be well-suited for MASW surveys.

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