Comparison of ReMi, and MASW Shear-wave velocity techniques with the CCOC borehole to 100 m, Santa Clara Valley

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This paper is an extract from

Asten, M.W., and Boore, D.M., eds., Blind comparisons of shear-wave velocities at closely spaced sites in San Jose, California: U.S. Geological Survey Open-File Report 2005-1169. [available on the World Wide Web at http://pubs.usgs.gov/of/2005/1169/].

2005

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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INTRODUCTION

Multi-channel analysis of surface waves, or MASW (Park et al, 1999), and refraction microtremor, or ReMi (Louie, 2001), are two of the most recently-developed surface techniques for determining shallow shear-wave velocity. Both ReMi and MASW acquisition require a linear array of vertically-oriented sensors using traditional seismic reflection/refraction equipment. Depth of investigation for both is primarily a function of array length and sensor resonant frequency, although in the case of MASW source energy is also a large factor. The sensor resonant frequency and the signal source primarily govern bandwidth. They differ fundamentally in the recorded source signal type. MASW is an active-source technique requiring an impulsive signal, such as from a sledgehammer or weight drop, or swept vibrational signal, such as vibroseis, to generate surface waves. Shear-wave velocity structure is derived from the fundamental mode Rayleigh wavefield generated by the source. ReMi, conversely, is a passive technique, recording ambient noise or microtremors ubiquitous in the urban environment. This contributed write-up presents shear-wave velocity depth models derived from MASW and ReMi techniques at the CCOC borehole.

DATA ANALYSIS

We interpret all data “blind” such that the presented interpretations were finalized prior to even the initial inspection of the borehole log. Acquisition parameters were selected to maximize the potential depth of investigation at the expense of detailed structure in the upper 5-to-10 m. The ReMi data were acquired with 4.5 Hz vertical geophones and 5-m sensor spacing. Array length was 220 m (45 sensors total). Data consisted of 20 ambient noise records of 30 seconds length transformed to the slowness-frequency (p-f) domain (McMechin and Yedlin, 1981) and stacked prior to dispersion analysis, as described by Louie (2001). A p-f domain image of the ReMi data with three picked dispersion curves is displayed in Figure 1. Because the ReMi method relies on a linear receiver array, there is no obvious way to distinguish event arrival azimuth, and therefore apparent phase velocities can be artificially high in the frequency slowness domain. Following the guidance of Louie (2001), we pick two extremal and a third “preferred” dispersion curve in between the extremal curves.

MASW data were acquired with the identical receiver array as the ReMi data. We used a 250 kg accelerated weight drop to generate surface waves. Whereas ReMi data required no pre-processing before transformation into the p-f domain, MASW data first required a geometric gain correction and benefited from trace muting of all wave phases not related to surface waves. The p-f analysis technique was almost identical to that of the ReMi data, with the primary difference being where the dispersion curve was picked on the p-f image, as shown in Figure 2. Because the source of the surface wave energy is known, the peak is assumed to be the correct dispersion curve location. Extremal dispersion curves were also picked on opposite sides of the peak. As indicated by the strong coherent peak in Figure 2, the weight drop source generated higher-frequency surface wave energy (to at least 30 Hz) than was generally observed in the microtremor data (Figure 1).

We derive shear velocity-versus-depth models using the iterative least-squares inverse modeling routine of Hermann and Ammon (2002). This code required the user to give an initial model of layers, layer thicknesses, Vs, Vp/Vs ratio (or Vp), and density. Synthetic testing showed that a reasonable initial model was important to the final inverted result. Our initial ReMi model was set to be a halfspace with 20 layers each of 10 m thickness, with an initial Vs set to an approximate average of the picked phase velocities. Maximum and minimum modeling depths were set using suggested guidelines discussed by Park et al. (1999). Previous studies have suggested that Rayleigh dispersion curves are much more sensitive to S-wave than to P-wave shallow velocity structure (Xia, et al., 1999; Liu et al., 2000; Louie, 2001). However, the code of Herrmann and Ammon (2002) requires either setting Vp or Vp/Vs for each inverted layer. The Vp/Vs ratios were set to a constant of 2, which is not unreasonable but possibly low for shallow deposits. However, the inversion result was relatively insensitive to this parameter. Because the modeling code required setting Vp or Vp/Vs a priori, we believe the P-wave velocity models are essentially meaningless and therefore not discussed in this write-up.

Modeling was terminated when RMS fit to the observed dispersion data was greater than 99% and mean velocity change was less than 5 m/s between iterations. Figure 3 presents the final inverted ReMi and MASW results. The solutions of the two methods are comparable to about 30 m depth, diverge to about 70 m and converge again at 100 m depth. MASW results tend to be higher than ReMi at the CCOC investigation site.

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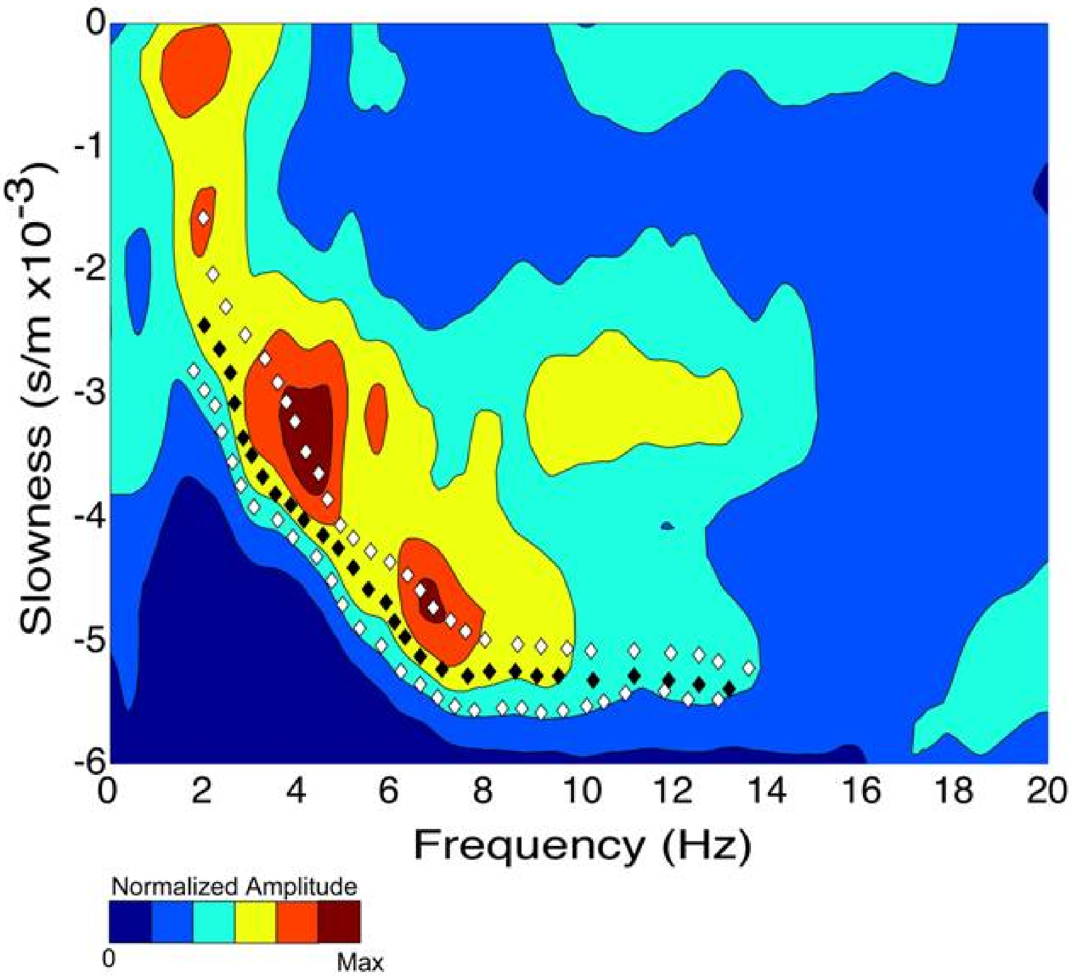

Figure 1. The p-f image of ReMi data acquired at borehole CCOC. Two extremal and one "preferred" dispersion curves were picked (white and black diamonds, respectively) and inverted for S-velocity structure.

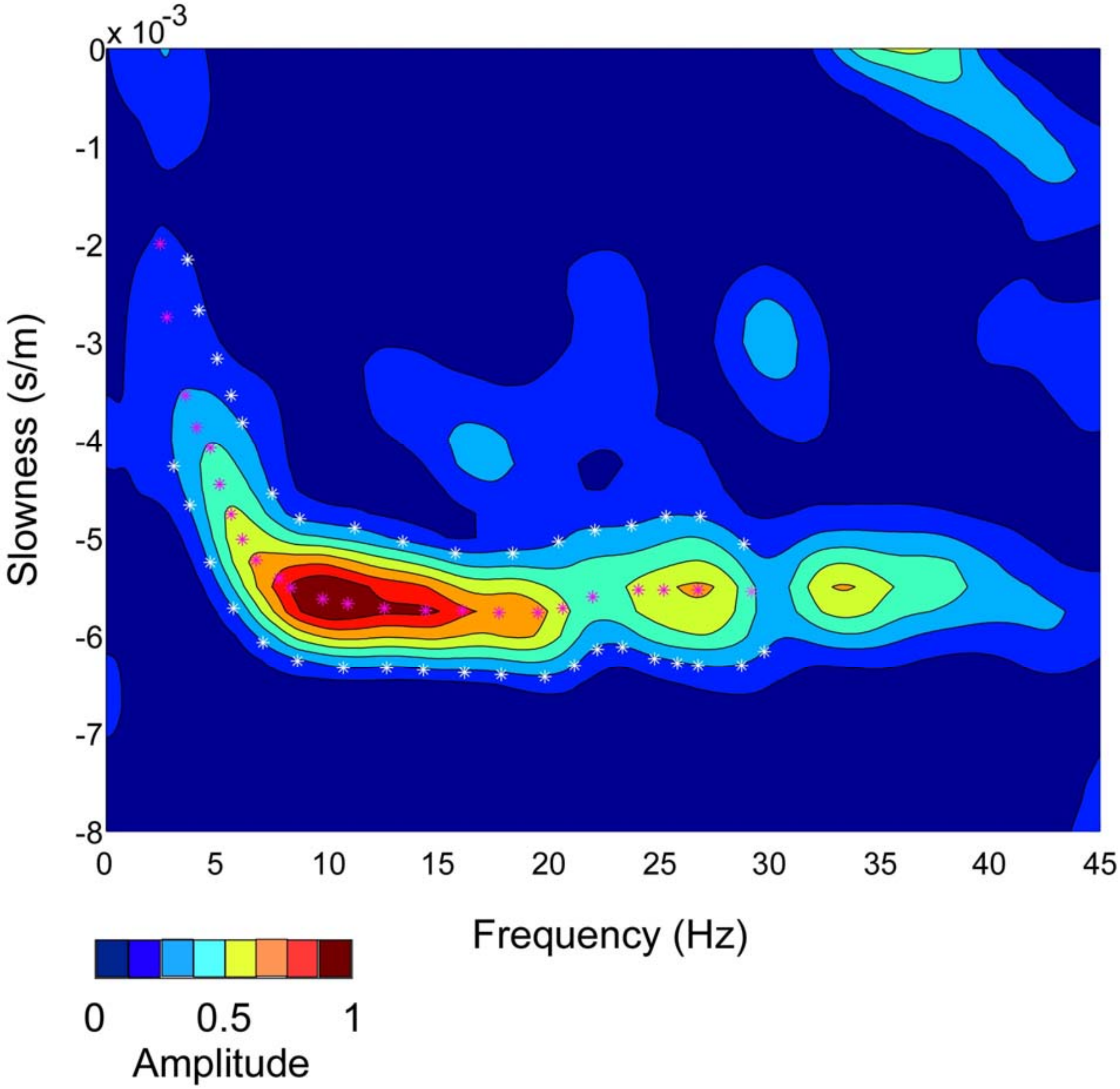

Figure 2. The p-f image of MASW data acquired at CCOC with extremal (upper- and lower-bound) dispersion curves picked as white stars and peak (preferred) dispersion curve picked with magenta stars.

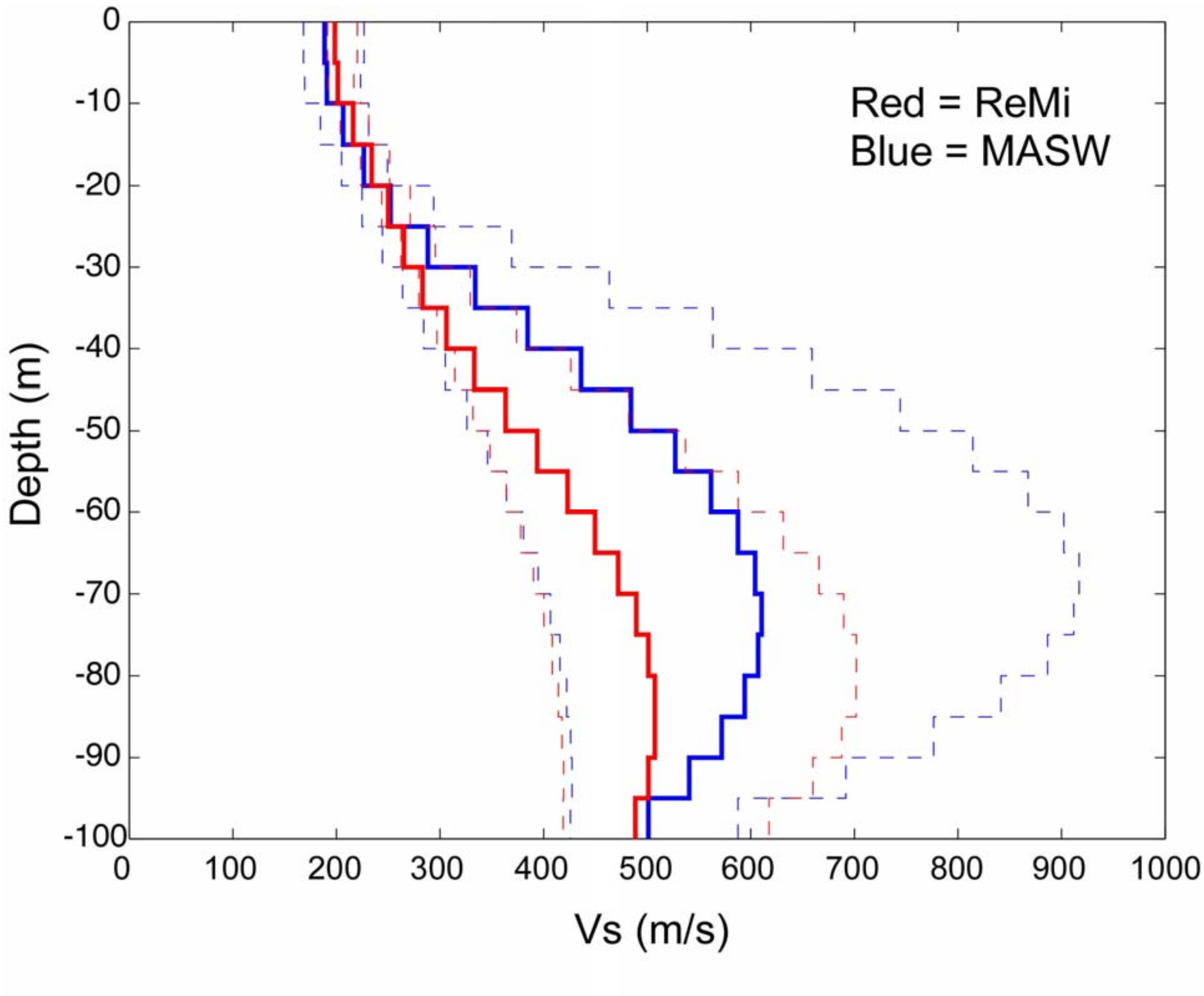

Figure 3. Velocity curves for the ReMi and MASW data acquired at CCOC by USGS. Extremal dispersion results shown by dashed lines and preferred solutions are shown as heavy solid lines. Each dispersion curve was inverted using a least-squares iterative algorithm (Herrmann and Ammon, 2002). Blue curves are MASW results and red curve are ReMi results.