SHALLOW-SEISMIC SITE CHARACTERIZATIONS OF NEAR-SURFACE GEOLOGY AT 20 STRONG-MOTION STATIONS IN WASHINGTON STATE

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Abstract

Shallow-seismic surveys have been conducted including multichannel analysis of surface waves (MASW), microtremor array measurements (MAM) and S- and P-wave refraction profiles to determine near- surface S- and P-wave velocity profiles at 20 selected Advanced National Seismic System (ANSS) station sites in Washington. These stations are located on various soil and rock sites. Determination of the S- and P-wave velocity profiles at each strong-motion site was followed by calculation of shear-wave velocities based on the National Earthquake Hazards Reduction Program (NEHRP) recommendation of average shear-wave velocity for the upper 30 meters (Vs30) of the soil column. This study improves our understanding of: 1) shallow site effects which can be incorporated into the seismic hazard assessment in Washington; 2) effects of soil and rocks sites on recorded ground motion signals; 3) ground motion attenuation curves in the Pacific Northwest, and 4) level of shaking and liquefaction potential in Washington. Specifically, at stations GNW and ALKI designated as reference sites, shear-wave velocities were determined by using both shallow seismic refraction and MASW+MAM survey techniques. The same seismic characterization methods were used for stations SFER and KCAM, which have very little amplitude information and poor phase determination of P- and S-wave arrivals; for stations WISH, ERW, LON, UWFH, BABE, SBES, LTY, and LYNC, which have lower-than-average short-period amplitudes; and for stations KNJH, ATES, SMNR, PAYL, KNEL, HART, SVTR and BSFP, which have higher-than-average short-period amplitudes. These results directly contribute to a better seismic hazard assessment and representation of ground motions for the USGS-ShakeMap and FEMA-HAZUS software products used for rapid emergency response and mitigation efforts in the Pacific Northwest.

Location of Shallow Seismic Surveys

In order to accurately quantify the near-surface seismic properties (Vs=shear-wave velocity, Vp=P-wave velocity, and Poisson's Ratio) with respect to depth, we conducted noninvasive active and passive surveys at 20 station sites in Washington

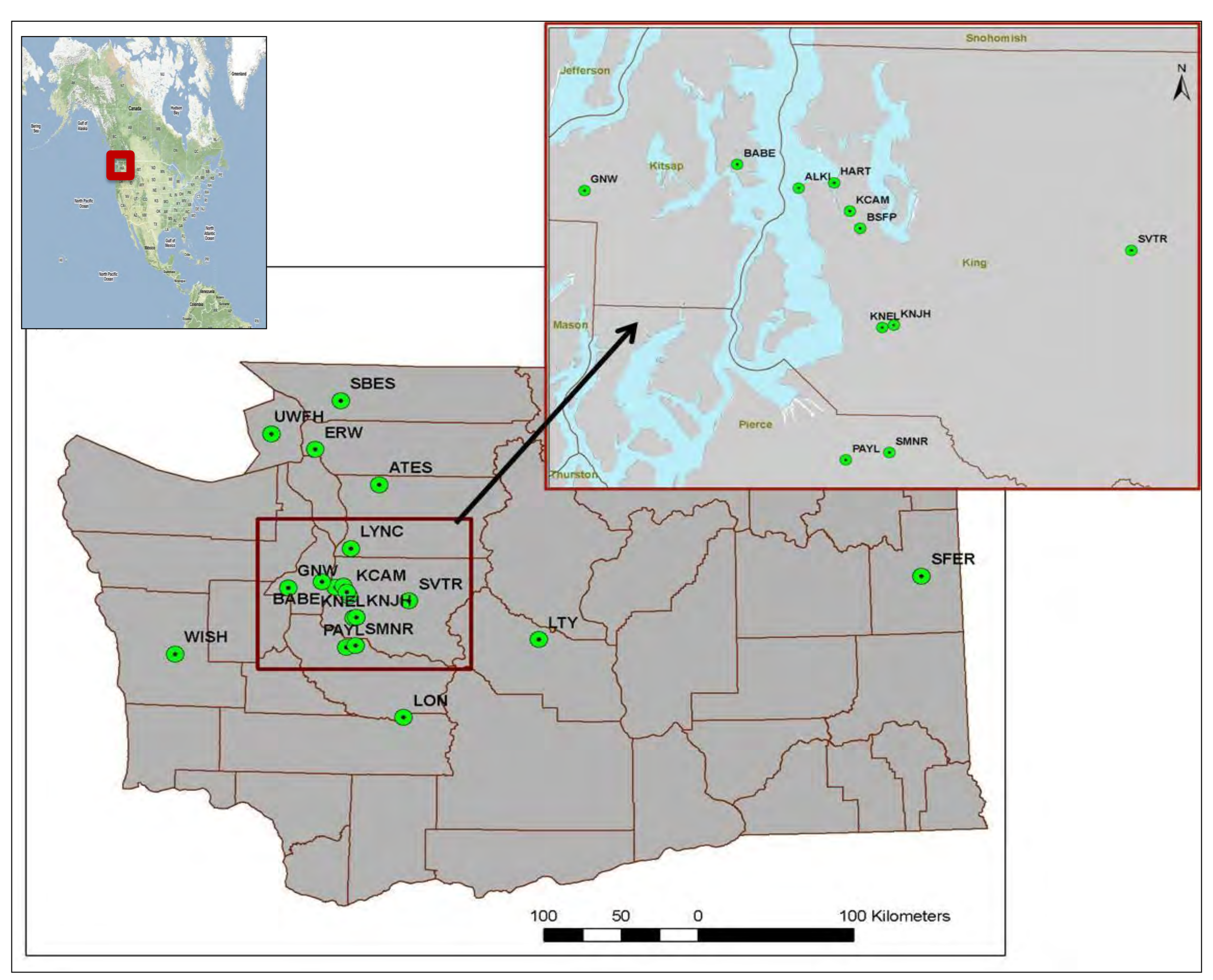


Figure 1. Shallow seismic survey locations.

Survey and Data Processing Methods

Multichannel Analysis of Surface Waves (MASW)

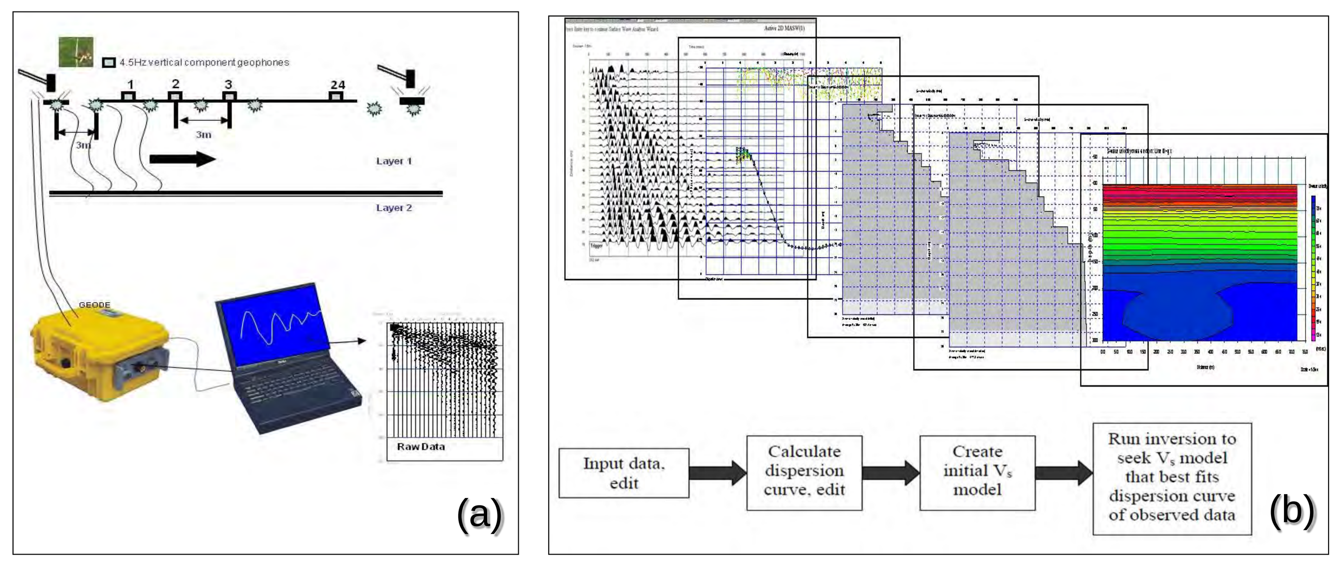


Figure 2. (a) The MASW field survey setup with 24 4.5-Hz, 24-geophone layout and 3 meter geophone and shot intervals, and example of the raw active seismic (MASW) data; and, (b) general steps of the 1D/2D Multichannel Analysis of Surface Waves (MASW) (Geometrics, 2006; Part et al., 1999; Xia et al., 2000).

Microtremor Array Measurements (MAM)

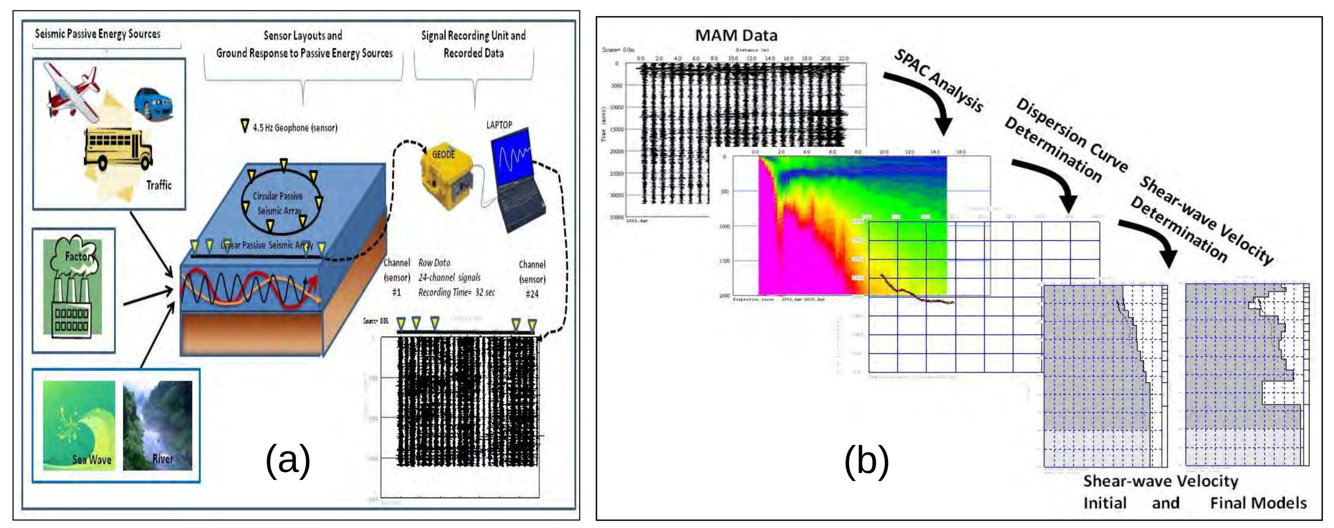


Figure 3. (a) Microtremor Array Measurement (MAM) passive seismic survey and its data (duration=32 seconds) on a 24-channel seismograph; passive seismic signals consisting of cultural and natural noise propagating at various wavelengths (interact with near-surface geology under linear and circular sensor arrays- an example of the MAM record is shown (bottom right). (b) Microtremor Array Measurement (MAM) processing steps: The MAM data are used as input for Spatial Autocorrelation (SPAC) analysis, resulted in a dispersion image which later edited for the best and most reasonable construction of the dispersion curve, then a 1-D shear wave velocity (Vs) profile is calculated from the dispersion curve; finally, Vs profile is generated after an inversion process.

P- and S-wave Refraction

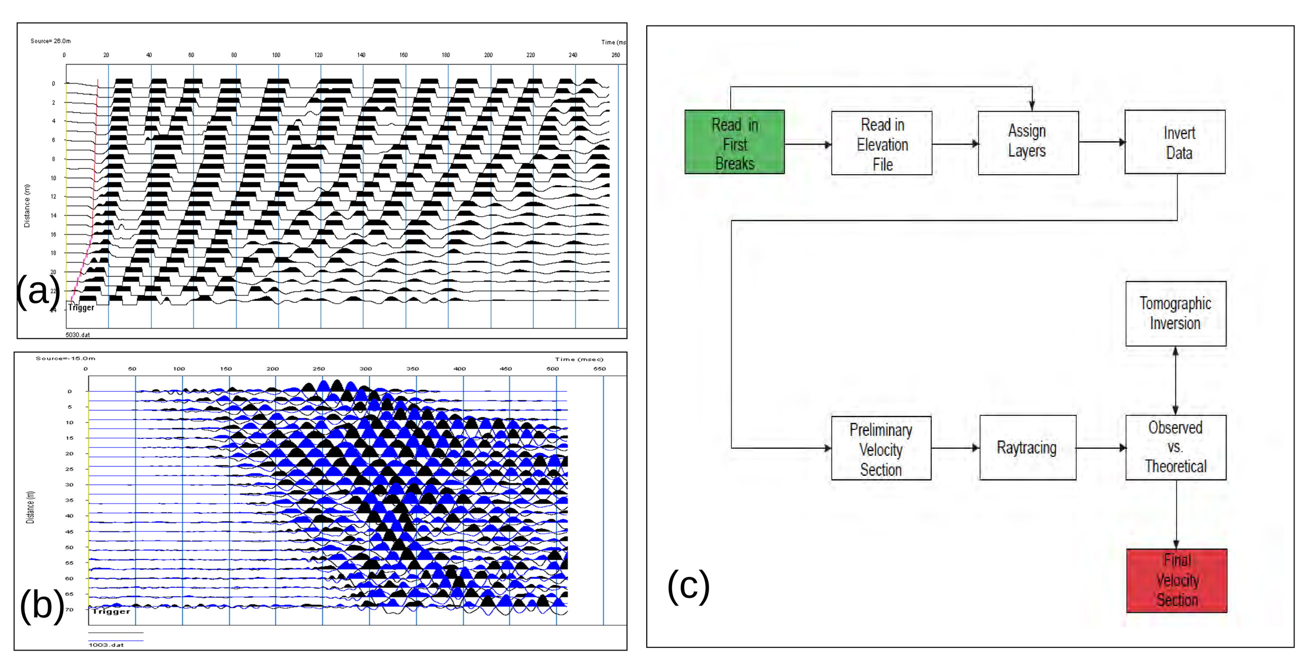


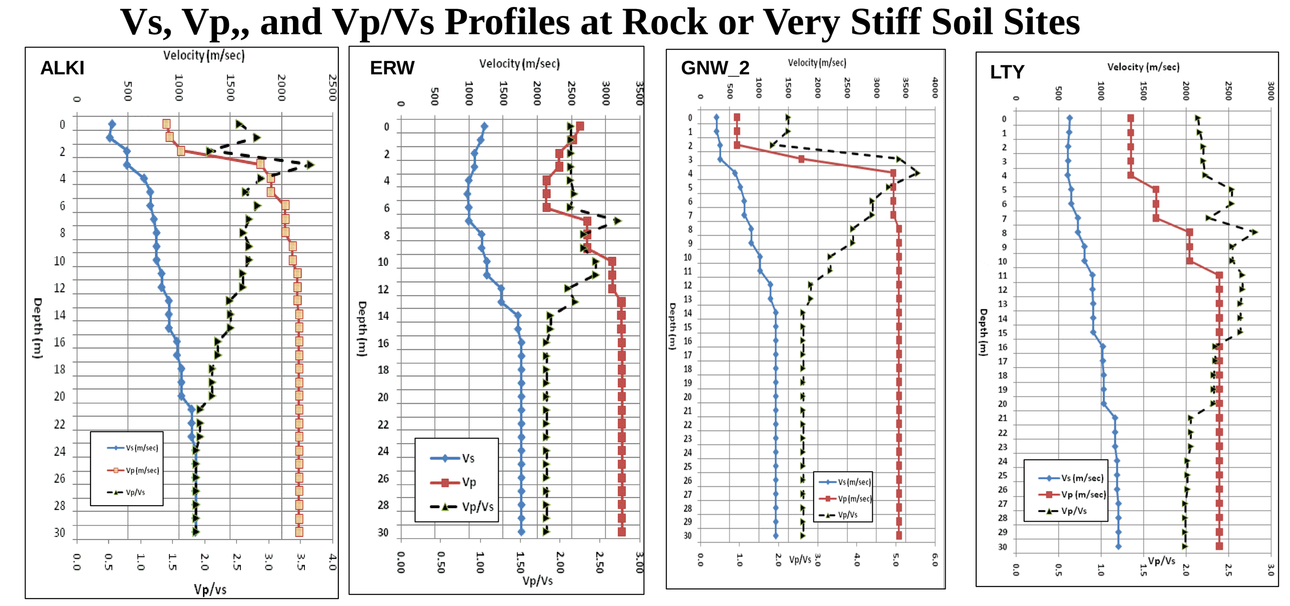
Figure 4. (a) and (b) show shot gathers of shear waves (recorded on horizontal geophones) and p waves (recorded on vertical-component geophones); (c) shows a flow chart for the general refraction data processing steps used (Geometrics, 2009; Zhang and Toksöz, 1998)

Results

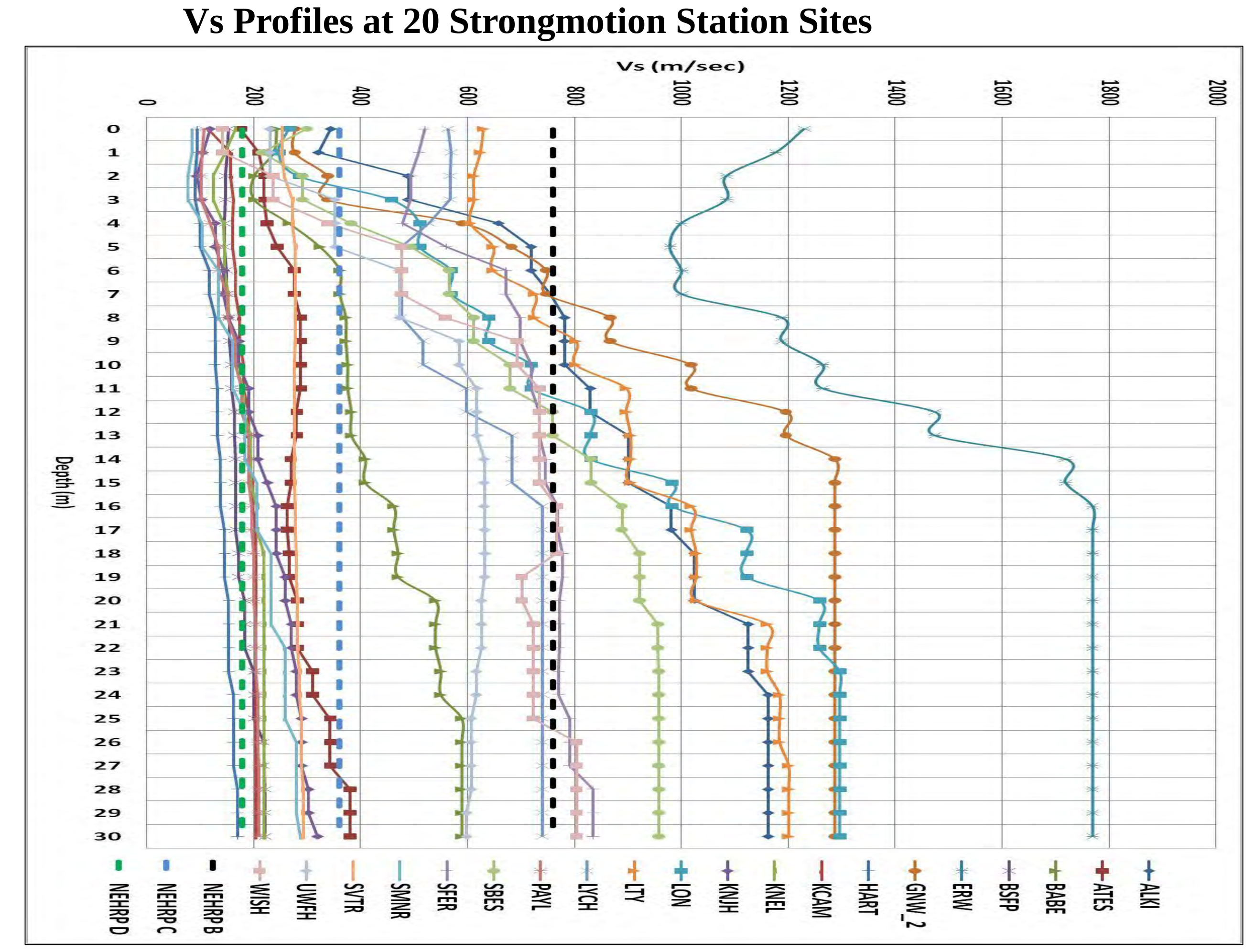
Table 1. Shallow-seismic survey (strong-motion station site) locations, survey types conducted , Vs30m which is the calculated average Vs to 30-m depth (International Code Council, 2006) and derived NEHRP site classifications from this study and from the current statewide NEHRP site class map for Washington (Palmer et al., 2004). S-wave refraction surveys were not run where sites were not suitable for a good geophone coupling to the ground (pavement area) or had a very noisy environment (such as station sites BSFP, KCAM, and HART). We considered MASW, MAM, and P-wave refraction as primary data acquisition methods for measurements of the Vs and Vp profiles (velocity vs. depth).

Station Name	Station Latitude (WGS84)	Station Longitude (WGS84)	Conducted Shallow Seismic Survey Methods	Vs30 (m/sec)	NEHRP Site Class (This study)	NEHRP Site Class (Palmer et al, 2004)
ALKI	47.57510	-122.41760	MASW, MAM, Refraction (SH and P)	**784**	**B**	D
ATES	48.23617	-122.06042	MASW, MAM, Refraction (SH and P)	272	D	C-D
BABE	47.60637	-122.53586	MASW, MAM, Refraction (SH and P)	390	C	C
BSFP	47.52000	-122.29833	MASW, MAM, Refraction (P)	171	E	D-E, E
ERW	48.45383	-122.62634	MASW, MAM, Refraction (P)	1416	B	B
GNW_2	47.56411	-122.82496	MASW, MAM, Refraction (SH and P)	815	B	B
HART	47.58377	-122.35010	MASW, MAM, Refraction (P)	131	E	E
KCAM	47.54400	-122.31850	MASW, MAM, Refraction (P)	183	D	D-E
KNEL	47.38052	-122.25193	MASW, MAM, Refraction (SH and P)	183	D	D-E
KNJH	47.38454	-122.22957	MASW, MAM, Refraction (SH and P)	184	D	E
LON	46.74996	-121.80883	MASW, MAM, Refraction (SH and P)	662	C	B
LTY	47.25573	-120.66601	MASW, MAM, Refraction (P)	872	B	B
LYNC	47.82555	-122.29384	MASW, MAM, Refraction (P)	628	C	C
PAYL	47.19260	-122.31401	MASW, MAM, Refraction (SH and P)	165	E	D-E
SBES	48.76814	-122.41633	MASW, MAM, Refraction (P)	614	C	B
SFER	47.61944	-117.36651	MASW, MAM, Refraction (SH and P)	614	C	C
SMNR	47.20442	-122.23273	MASW, MAM, Refraction (SH and P)	160	E	D-E
SVTR	47.49576	-121.78159	MASW, MAM, Refraction (SH and P)	271	D	D-E
UWFH	48.54593	-123.01324	MASW, MAM, Refraction (P)	489	C	B
WISH	47.11698	-123.77118	Downhole, MASW, MAM, Refraction (P)	485	C	C

Vs, Vp,, and Vp/Vs Profiles at Rock or Very Stiff Soil Sites



Vs Profiles at 20 Strongmotion Station Sites



Conclusions

- Shear-wave velocities estimated in this study directly contribute to a better seismic hazard assessment and representation of ground motions for the USGS-ShakeMap and FEMA-HAZUS software products (in terms of NEHRP site class) used for rapid emergency response and mitigation efforts in Washington and the Pacific Northwest region.
- NEHRP site classifications determined at station sites are generally consistent with preliminary site class map (Palmer et al., 2004).
- MASW and MAM methods are more practical, fast, and reliable ways to characterize the sites and allow us to record P- and S-waves (in-plane) at the same time.
- The 2D MASW method roughly reveals information about the site's subsurface horizontal variations in Vs, which is a useful information for site specific studies such as liquefaction and slope stability.
- Out-of-plane shear waves (SH), including surface waves (Love waves), showed longer durations compared to Rayleigh waves recorded (using the MASW method) at station ATES. This indicates very loose soil layer (high impedance contrast) near the surface.

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Acknowledgments

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J Perrault and R Cakir answer earthquake-related questions raised by curious K-12 students at ATES.

C. Maffucci and R Cakir check field data quality at UWFH.

T. Walsh generates seismic energy using the sledgehammer at UWFH.

C. Maffucci finds a best place to run the seismic survey