Rapid seismic surveys for non-intrusive fault location, basin structure, critical-zone characterization, and site class for building-code compliance

Poster B-318

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1. Abstract

Seismic surface-wave-arrays offer the opportunity to perform one geophysical survey yielding seismic site class along with a more comprehensive site investigation including assessments of fault location, critical zone characterization, depth to bedrock, and even P-wave velocity and Poisson's ratio. Building-code-compliant surface-wave surveys, when processed and interpreted with Terēan software, provide this full range of results. The resulting cross sections of shear-wave velocity often locate surface faulting with 3 m accuracy, demonstrated on strands of the Calaveras fault in Pleasanton, Calif. and the Las Vegas Valley faults in Nevada, among others. ASCE/SEI Standard 7-22 has been adopted into building codes by countries, states, and municipalities around the world. Chapter 20 describes new standards for determining seismic site class that encourage geophysical surveying rather than cone penetrometer or standard penetration testing. Invasive methods can fail to achieve compliance because of tool refusal or difficulty for intrusive methods to access sites. For non-intrusive geophysical surveying to achieve code compliance it is important for geotechnical engineers to employ geophysical survey methods effective at determining the time-averaged shear-wave velocity from the surface to 30 m depth, known as Vs30. Without such measurements, taking the default seismic site class may lead to over-design of building structures, inflated construction costs and extended project timelines. Most sites require less than one hour to complete for Vs30 measurement, including narrative report generation. This technology increases the ease of data collection with an untethered, triggerless hammer and the ability for the same array of 24, 4.5 Hz geophones to collect S- and P-wave data simultaneously. Many case histories at scales from 5 m to 1000 m serve to demonstrate these rapid and comprehensive results, including assessments of basin structure to kilometer depths. Simpler geophysical surveys with more comprehensive results allow engineers and geologists to more efficiently complete safety and environmental assessments.

2. Introduction

The availability of lower-cost and more rapid subsurface seismic imaging using Terēan ReMi® software and solutions is allowing industries and agencies to address a wide variety of challenges, including:

- Critical-zone characterization
- Depth to bedrock and rippability
- Earthquake fault location and characterization
- ASCE 7-22 Building Code compliance, construction costs, urban planning
- Resource exploration & development: Water, Geothermal, Critical Minerals
- CVM construction and basin effects on earthquake shaking

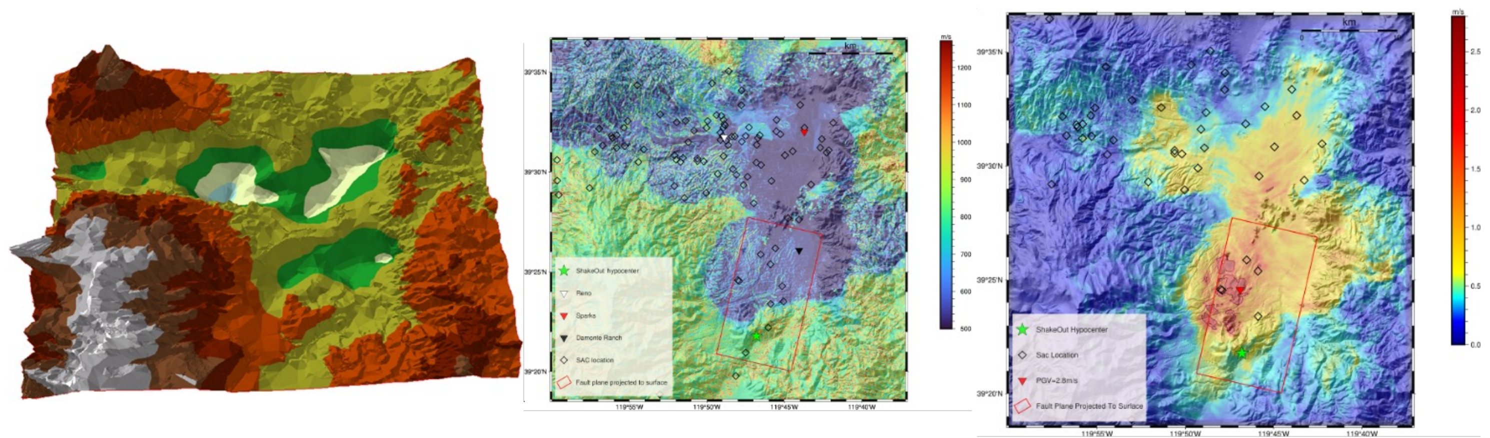

Figure 1: Illustrations from Eckert et al. (2021) of the Reno-area, NV community velocity model: (left) 3D Reno basin depth and bedrock topography, (center) surface shear-wave velocity, and (right) physics-based scenario shake map PGV to 3 Hz.

Validation in Peer-Reviewed Publications

This poster shows new examples of the application of seismic surface-wave technologies that have long been demonstrated and accepted in the peer-reviewed scientific literature:

- Comparisons of ReMi Vs(z) profiles and Vs30 to boreholes by Stephenson et al. (2005)
- Efficient large-scale, large-N measurements of hundreds to tens of thousands of sites by Thelen et al. (2006) and Pancha et al. (2017a)
- Deep ReMi recovering basin thickness up 1 km, Z1.0 & Z2.5, and matching gravity by Pancha et al. (2017b)
- Two ReMi papers are in the *COSMOS International Guidelines for Applying Noninvasive Geophysical Techniques to Characterize Seismic Site Conditions*, Louie et al. (2022) and Pancha & Apperly (2022)

3. Methodology

ReMi analysis is a method of recording active and passive sources on a linear array of vertical geophones (Louie et al., 2022). Sufficient data will reveal fundamental-mode Rayleigh-wave dispersion of waves traveling in the array direction. Shear-wave velocities profiles modeled from subarray dispersions are arranged into 2D Vs sections and 3D Vs volumes.

Figure 2: Photos of ReMi field data collection. (left) UNR interns installing a Fairfield Nodal. (right) ReMiNode® deployment. Both in Reno area.

4. Results

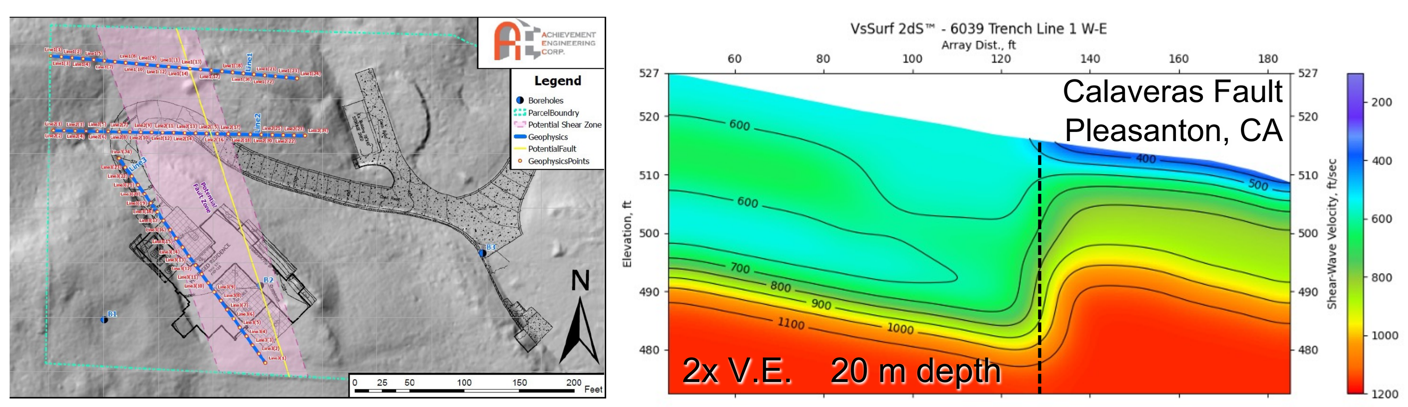

Figure 3: Terēan assisted Achievement Engineering to locate the Calaveras fault in Pleasanton, CA using 3 arrays 70 m long of industry-standard ReMiDAQ® recording of 24 5 Hz geophones (left). Each array took 30 min to complete, including 15 min of recording. Active-source hammer blows were included. The sections locate the fault with an accuracy of 3-5 m. White in the section (right) is above the topographic surface.

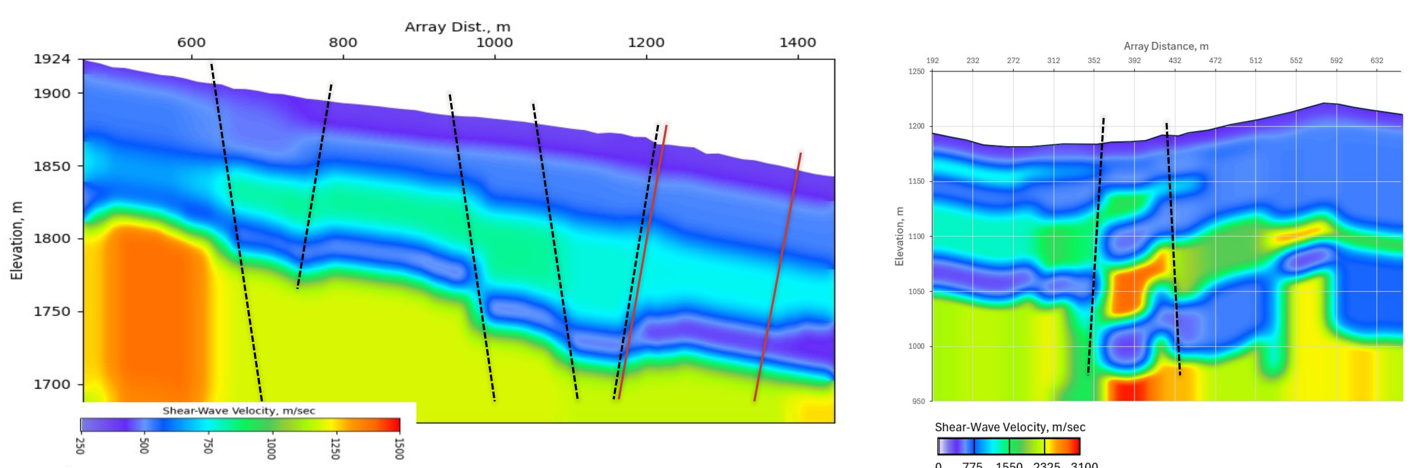

Figure 4: Anglo Gold Ashanti recorded 0.8-1.9 km-long arrays of 60-120 4.5 Hz vertical geophones for 3 hours in remote areas of Nevada with their Terēan ReMiNode® system to produce these sections 450-670 m long and 200-300 m deep, at 2x V.E. The sections show alternating hard (green) and soft (blue) layers of volcanic over Paleozoic stratigraphy, with indications of normal faulting (located to 20 m) and high-velocity mineralization (orange).

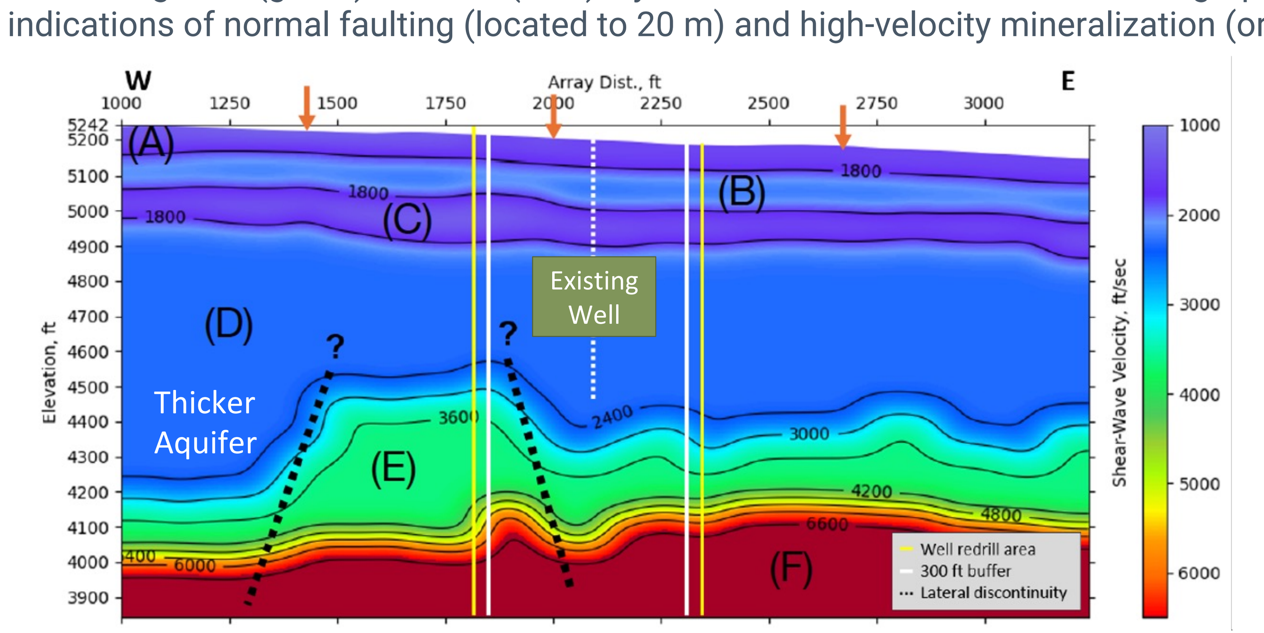

Figure 5: Exploration of municipal aquifer geometry by the Truckee Meadows Water Authority (TMWA) in Reno, NV. A 1.2 km-long array of 106 4.5 Hz vertical geophones recorded for 3 hours by a Terēan ReMiNode® system producing this section 670 m long and 360 m deep, at 2x V.E. Plio-Pleistocene rocks with water-production potential (purple and blue, A-D) sit above older Tertiary rocks with less capacity (green and red, E-F). The tops of the older rocks do not show any offsets consistent with offsets in the shallow layering, constraining the total Quaternary vertical offsets of any active faulting to <6 m. Orange arrows point to potential fault scarps mapped 50 years ago but never examined further.

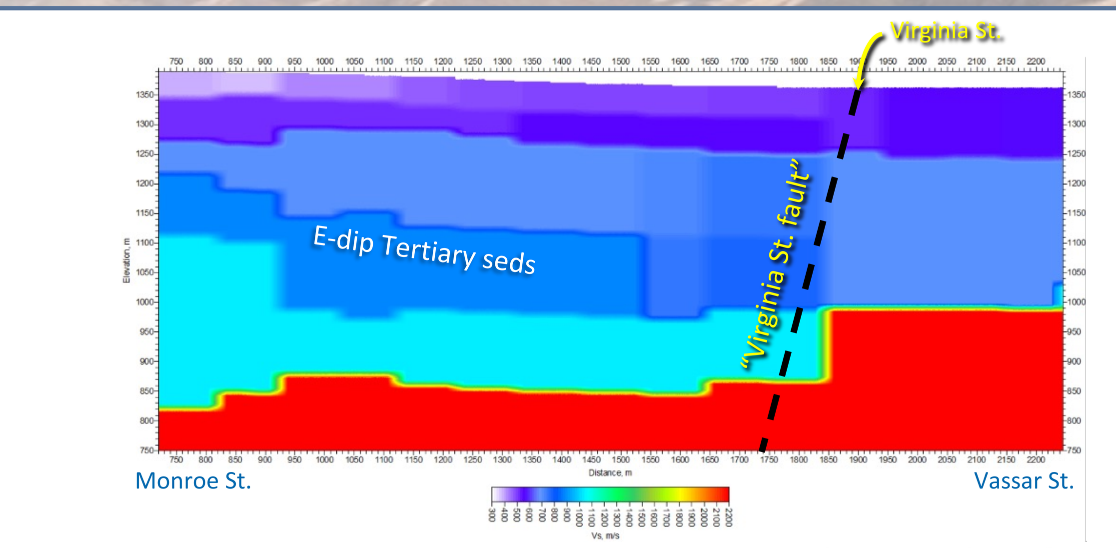

Figure 6: Reno, NV Virginia Street Deep ReMi section 1.3 km long resulting from 3 hours of recording by 60 iSeis Sigma nodes in an array 3 km long, each with a 4.5 Hz vertical geophone. Quaternary alluvium (purple) sits above late-Tertiary clastics and diatomite (blue) that dip eastward into a steeply west-dipping normal fault in the Mt. Rose system. The fault offsets the Miocene volcanics (red) by 150 m.

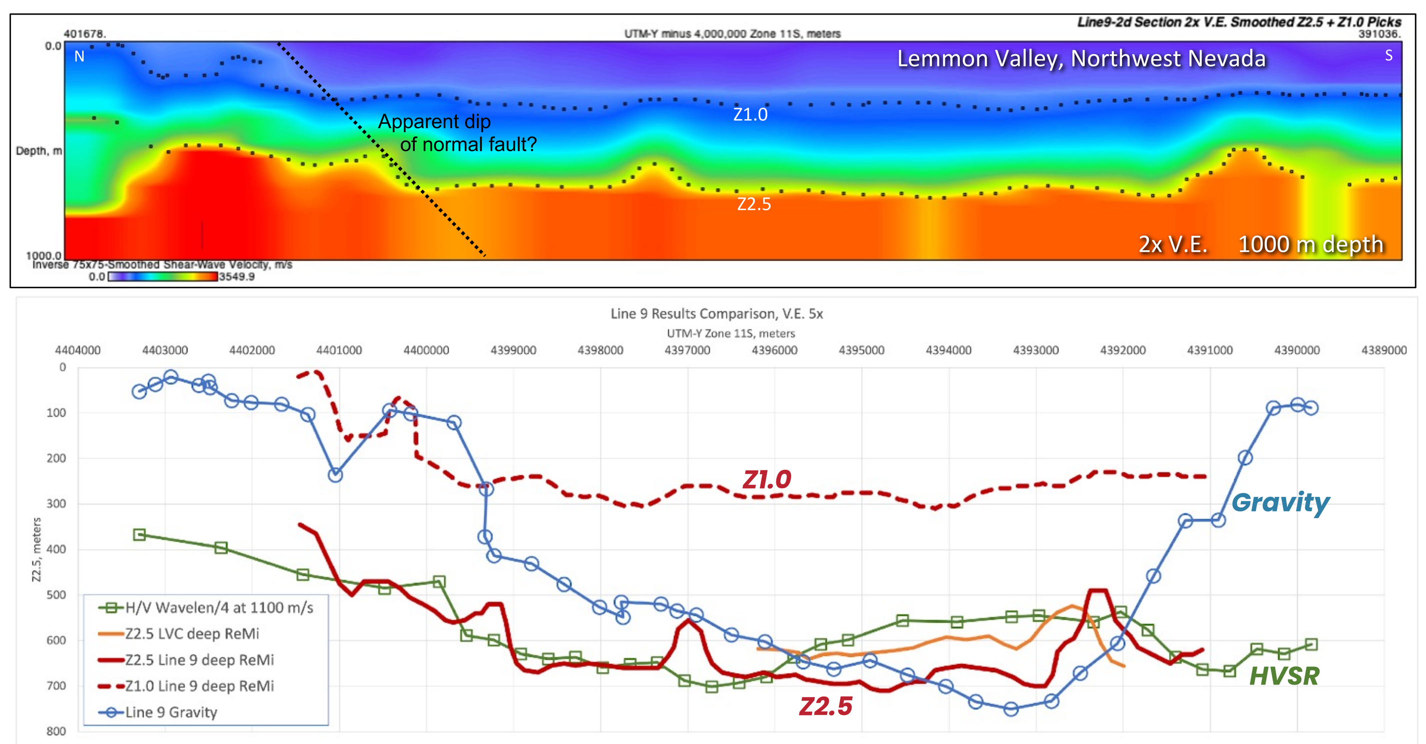

Figure 7: (above) Lemmon Valley, NV 10.6 km-long Deep ReMi section showing Z1.0 at the base of Plio-Pleistocene sediments (purple), Z2.5 as deep as 750 m at the base of earlier Tertiary volcanics and sediments (blue and green); Mesozoic and earlier basement (orange and red). (below) Z matches to gravity (Smith et al., 2025) and HVSR analyses. The ReMi and HVSR results used 13 hours of recording on 44 Fairfield 3C 5 Hz nodes.

5. Conclusion/Discussion

Both Geotechnical and ReMi surveys are consistently meeting industry and agency needs for subsurface characterization.

- Surveys to 50 m depths over 100 m-long section completed in 30 minutes.
- Surveys to 1 km depths over lines 10 km long completed in one day.

Terēan is ready to engage with researchers to:

1. Collaborate on projects benefitting from seismic imaging, from the proposal through execution to the scientific reporting stages;
2. Enable students to add seismic imaging to their thesis projects; and
3. Enable instructors to teach their undergraduates seismic surveying and analysis skills that are in great demand by industry.

6. References Cited

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