Geophysical Site Characterizations at Strong Motion Stations in Southern California

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U.S. Geological Survey

an NSF+USGS center

SCEC 3D Site Effects Workshop
5 May 2015 at SCEC Media Center, USC

Overview:

- Perspective on existing and future V_s profile data… V_{s30}
    - State of the Art
    - Limitations
    - Successes
    - Future Work

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Outline:

- U.S. Compilation of V_{S30} → V_s profile database.

- V_s profiles from non-invasive techniques in Southern California.

    - "ARRA-Funded V_{S30} Measurements Using Multi-Technique Approach…" by Yong *et al*. (2013; USGS OFR 2013-1102)

    - "Geophysical Characterizations of Seismographic Station Sites…—The Use of Active Love Wave Techniques." by Martin *et al*. (2014; Proceedings of 10th NCEE Conf.)

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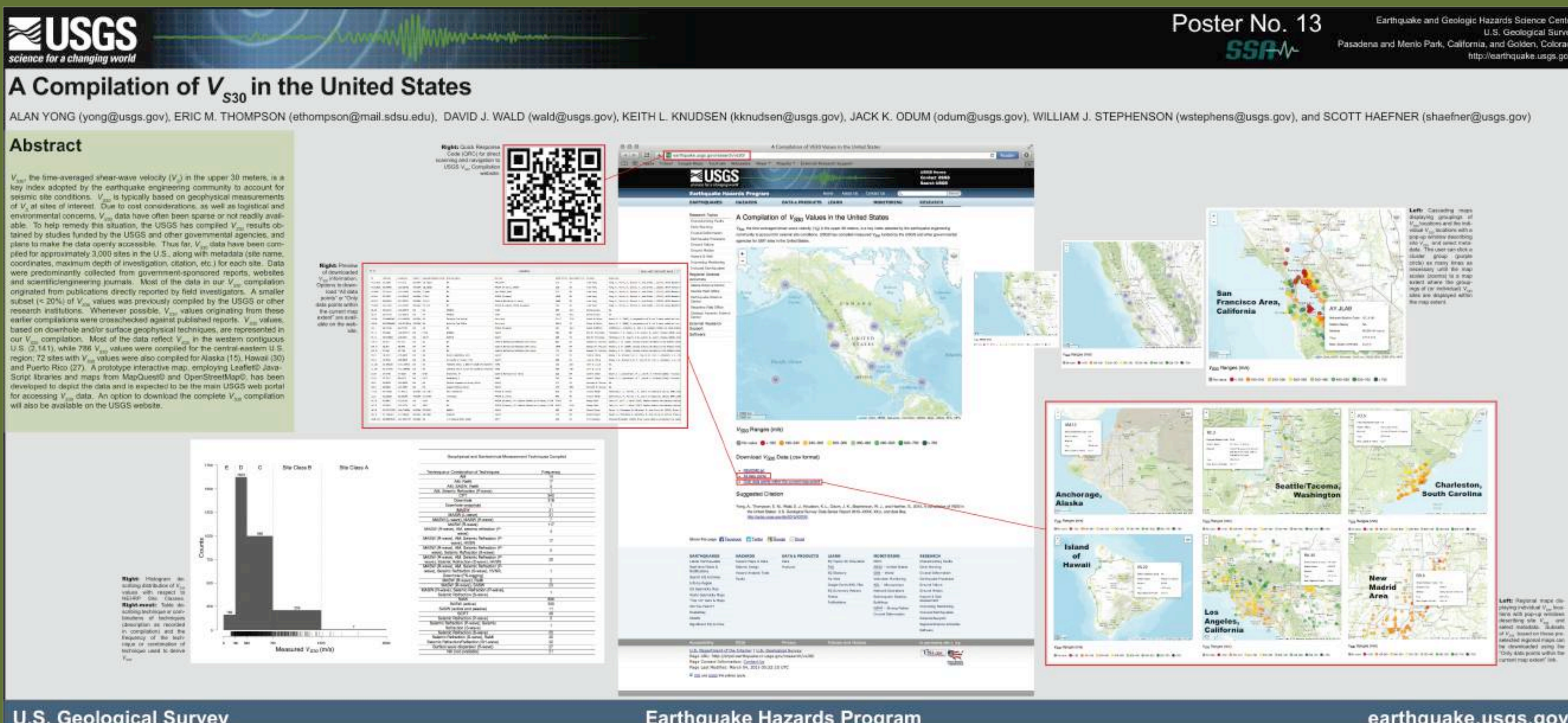
USGS V_{s30} Compilation for the U.S.

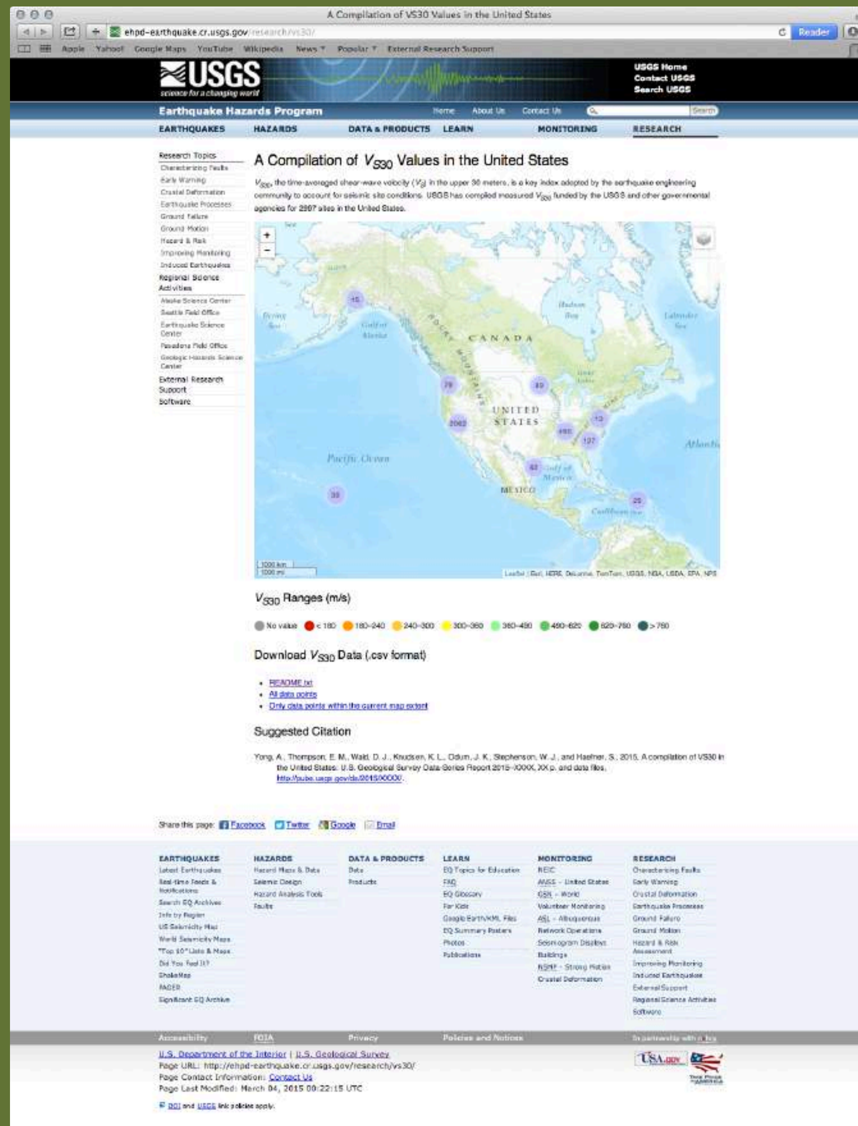
http://earthquake.usgs.gov/research/vs30/



http://earthquake.usgs.gov/research/vs30/

USGS V_{S30} Compilation for U.S.

Yong *et al*. (2015; USGS DS *in prep*.)



A Compilation of V_{S30} Values in the United States

V_{S30}, the time-averaged shear-wave velocity (V_S) in the upper 30 meters, is a key index adopted by the earthquake engineering community to account for seismic site conditions. USGS has compiled measured V_{S30} funded by the USGS and other governmental agencies for 2997 sites in the United States.

V_{S30} Ranges (m/s)

No value · < 180 · 180–240 · 240–300 · 300–360 · 360–490 · 490–620 · 620–760 · > 760

Download V_{S30} Data (.csv format)

- README.txt
- All data points
- Only data points within the current map extent

Suggested Citation

Yong, A., Thompson, E. M., Wald, D. J., Knudsen, K. L., Odum, J. K., Stephenson, W. J., and Haefner, S., 2015, A compilation of VS30 in the United States: U.S. Geological Survey Data-Series Report 2015–XXXX, XX p. and data files, http://pubs.usgs.gov/ds/2015/XXXX/.

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- Characterizing Faults
- Early Warning
- Crustal Deformation
- Earthquake Processes
- Ground Failure
- Ground Motion
- Hazard & Risk
- Improving Monitoring
- Induced Earthquakes

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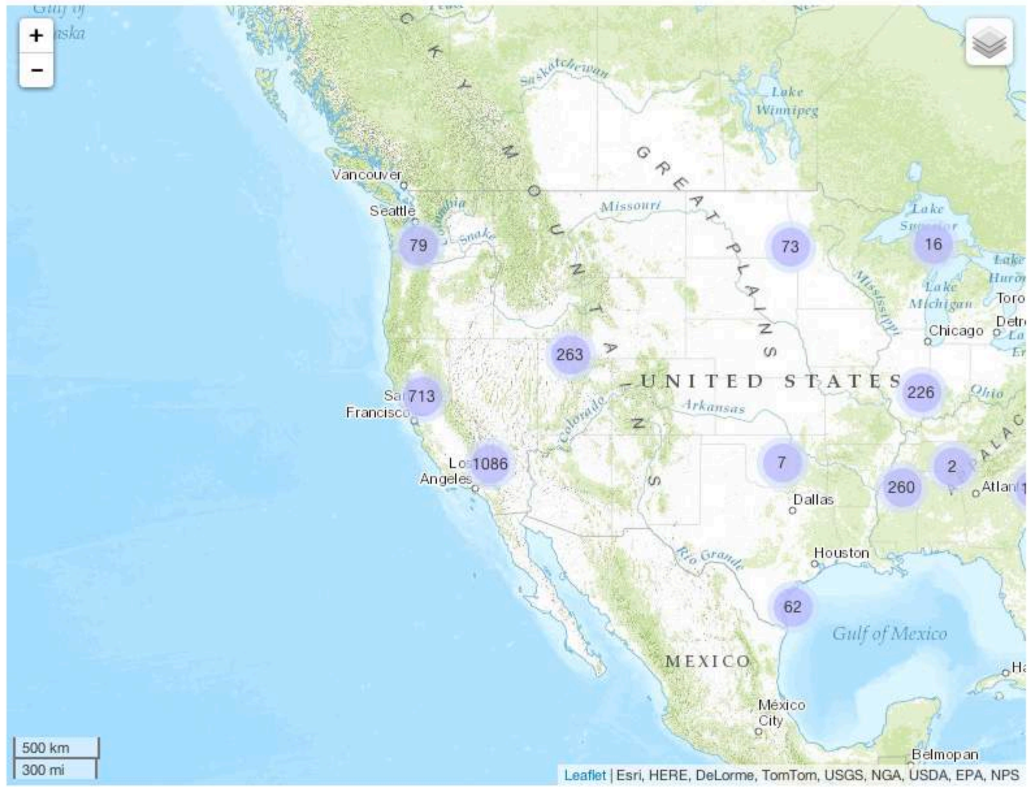

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earthquake.usgs.gov/research/vs30/

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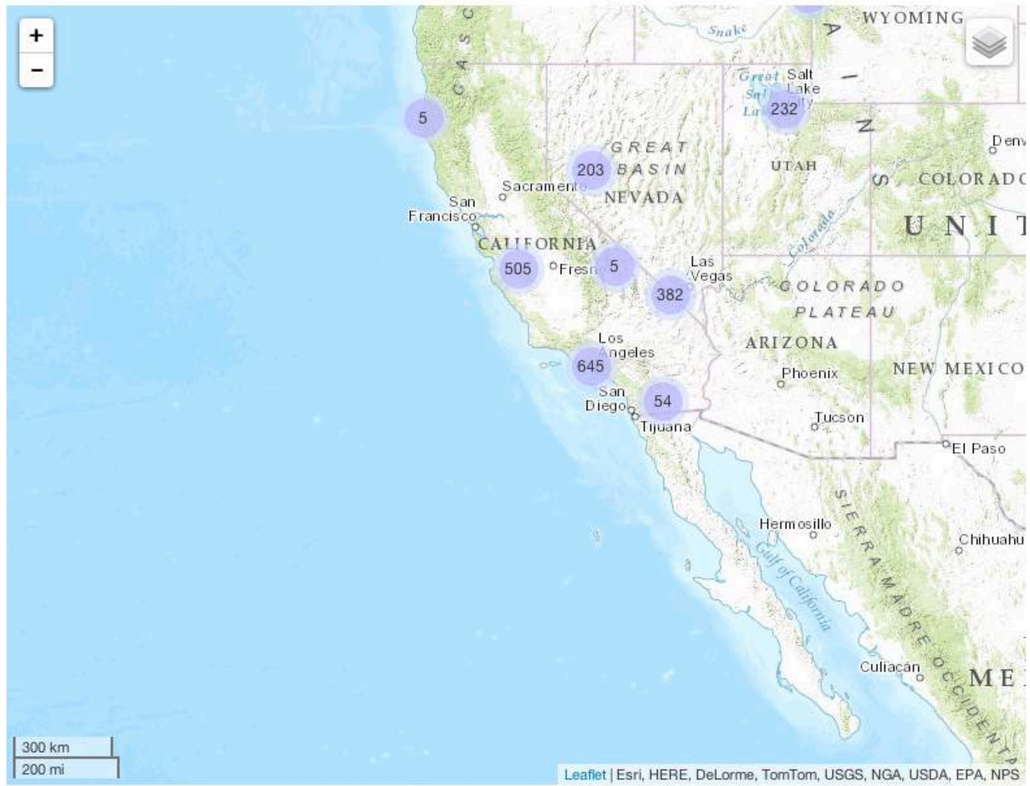

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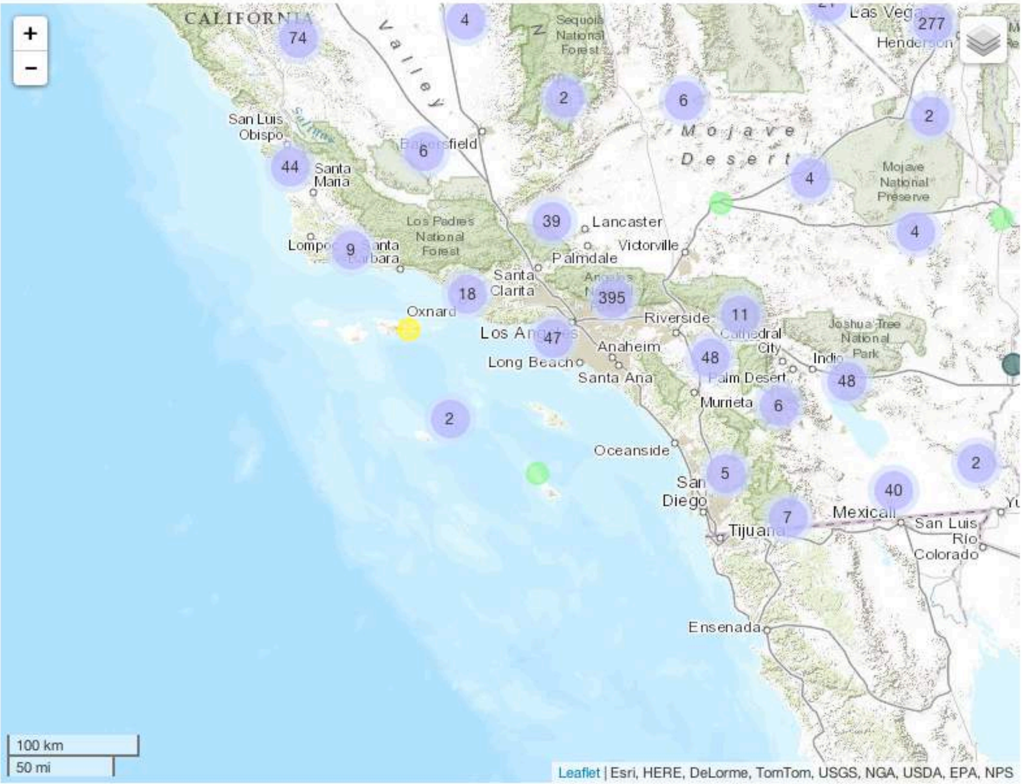

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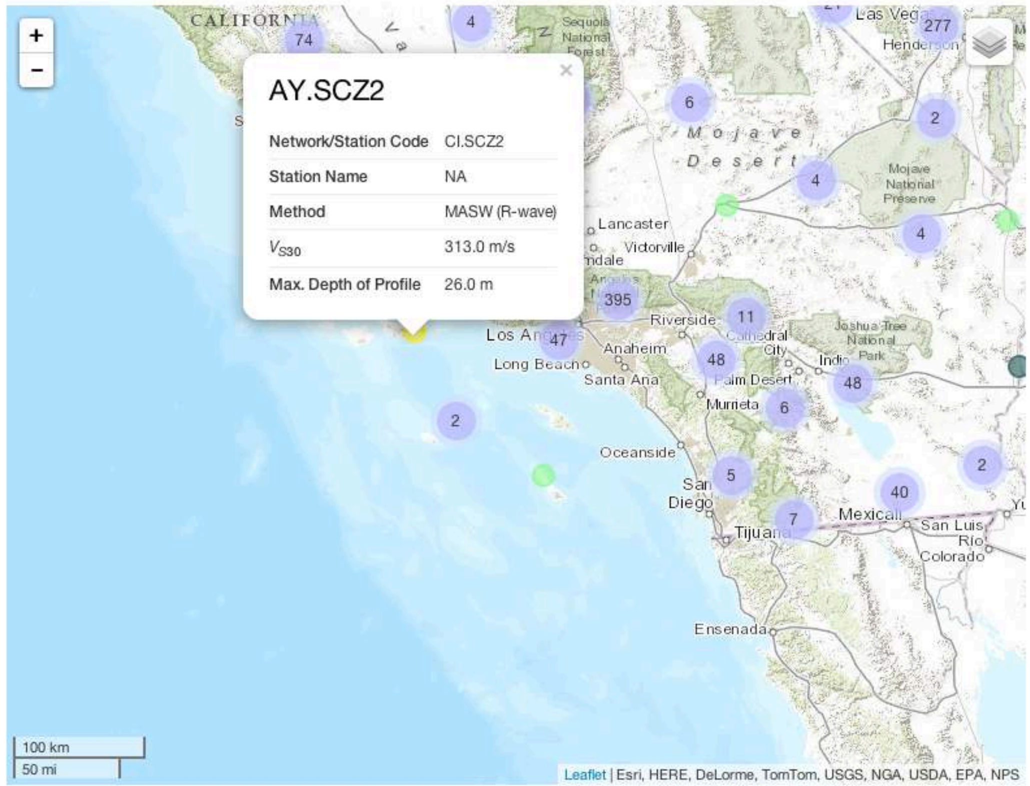

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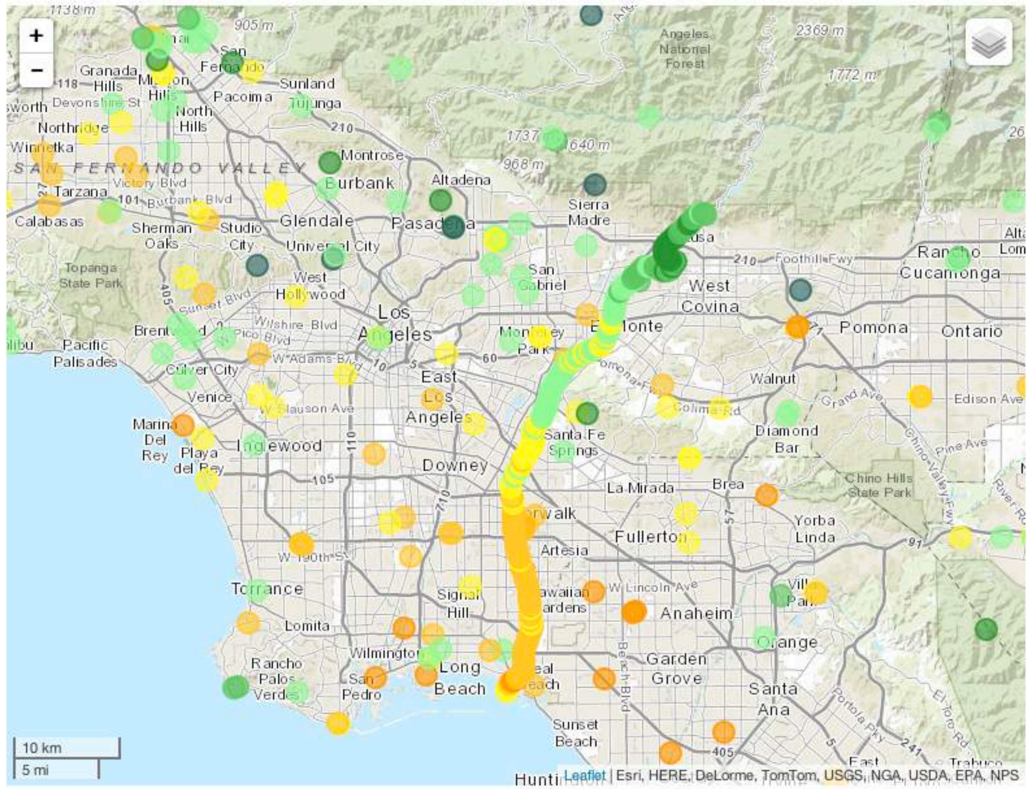

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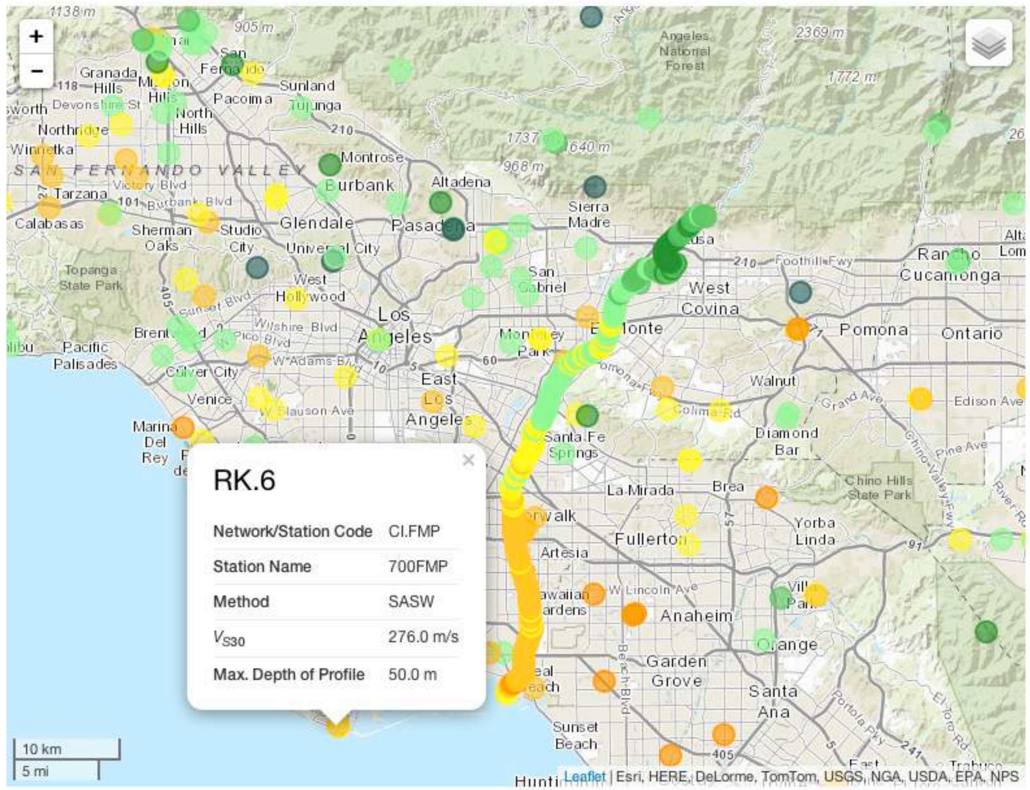

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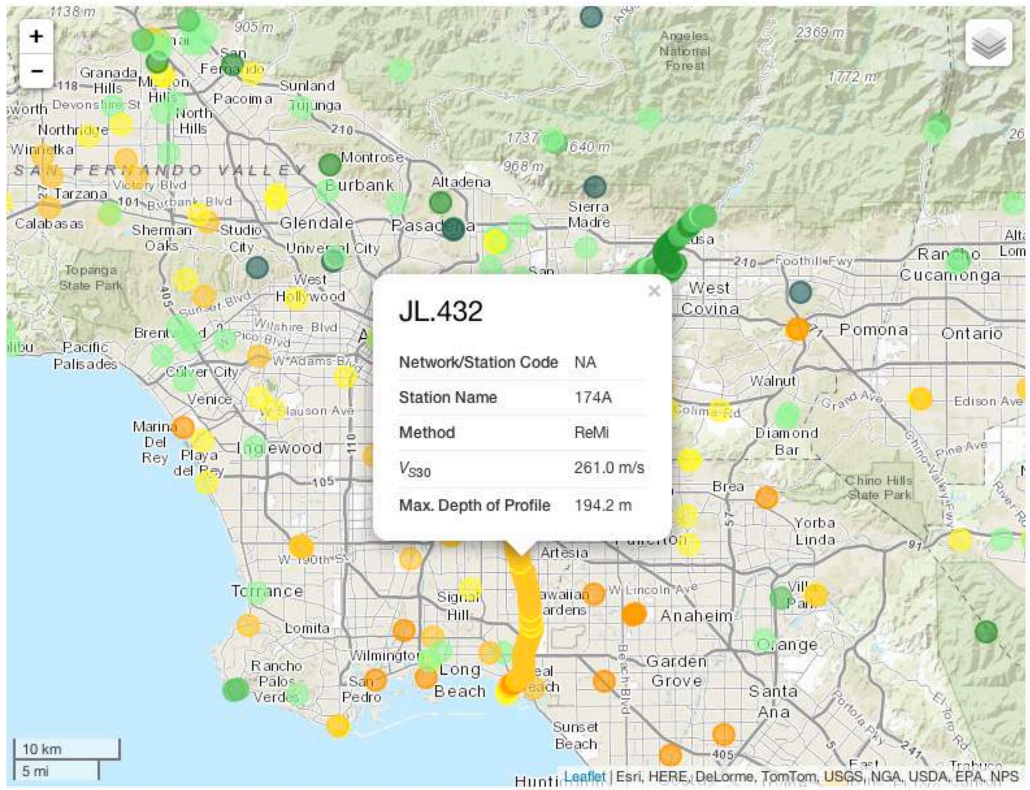

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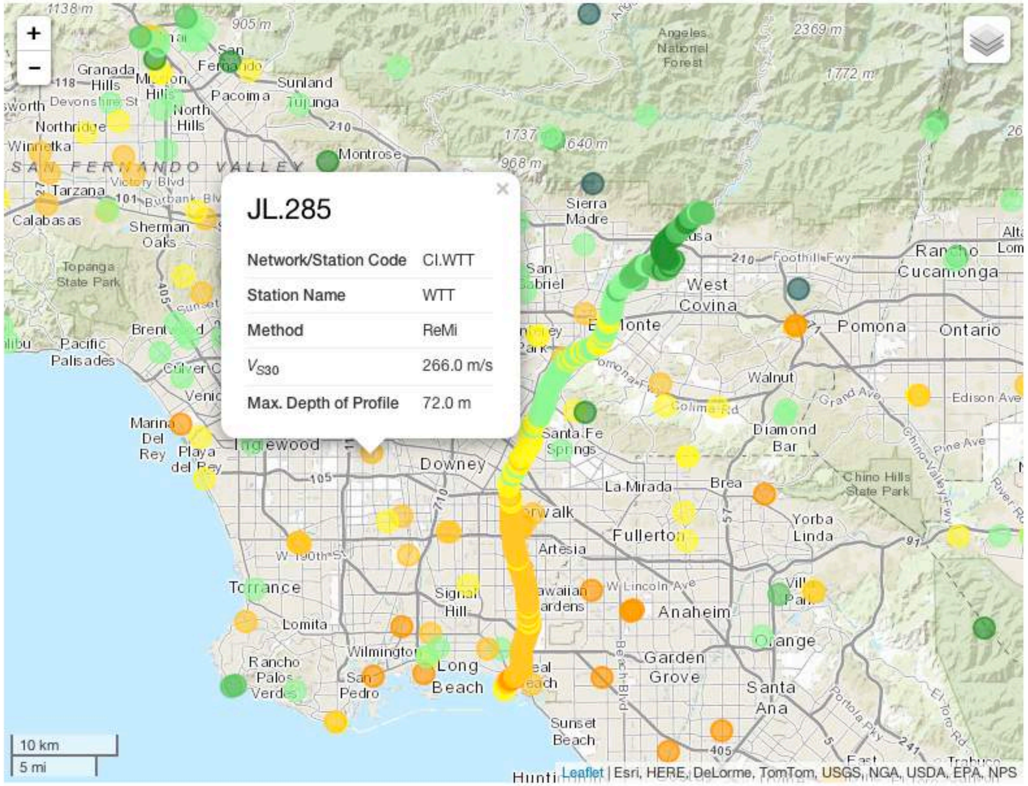

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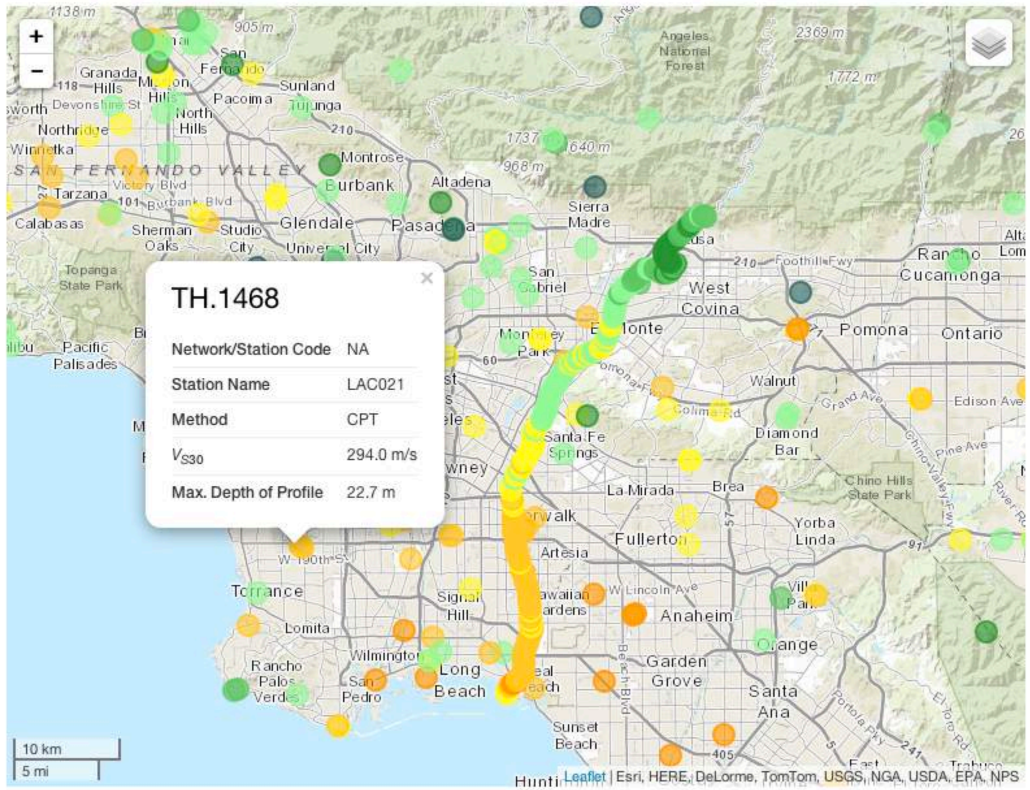

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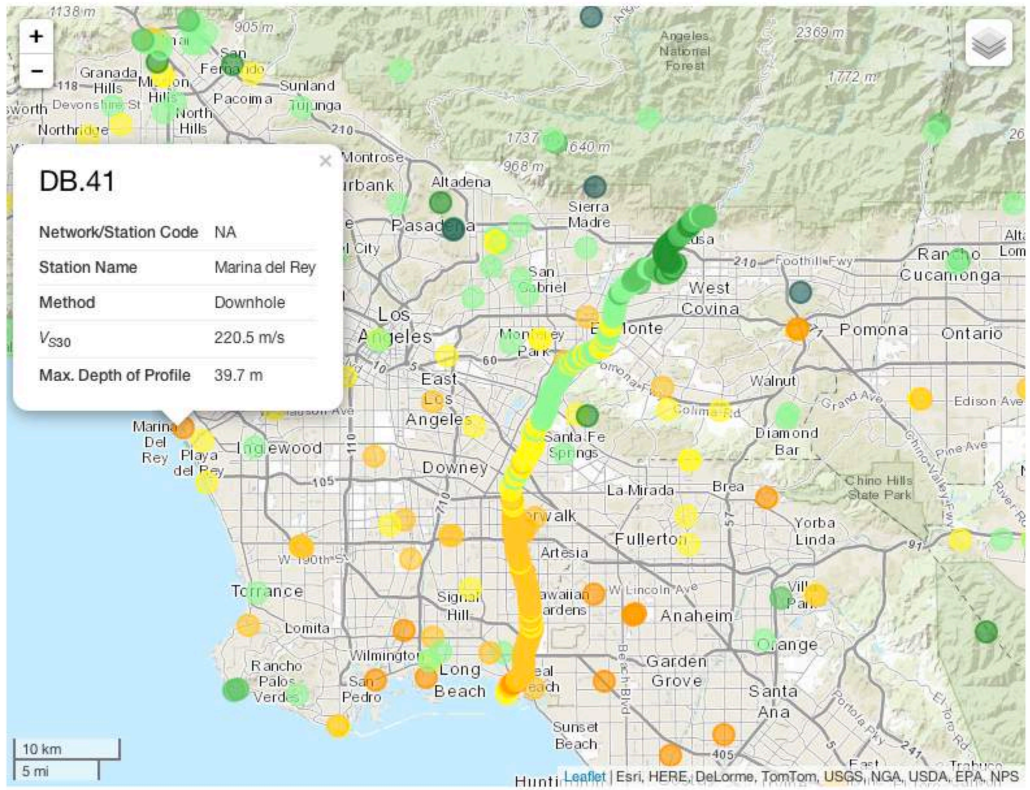

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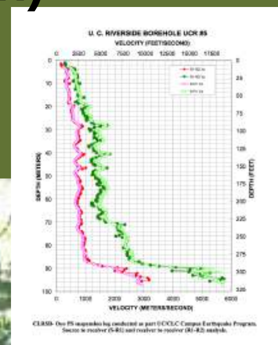
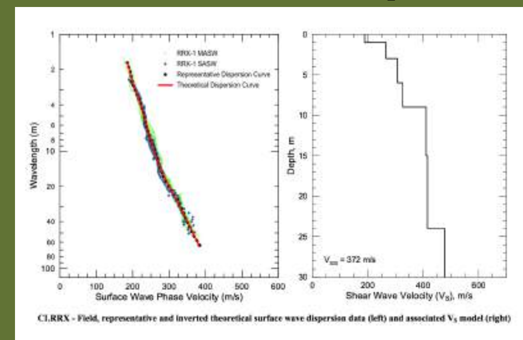
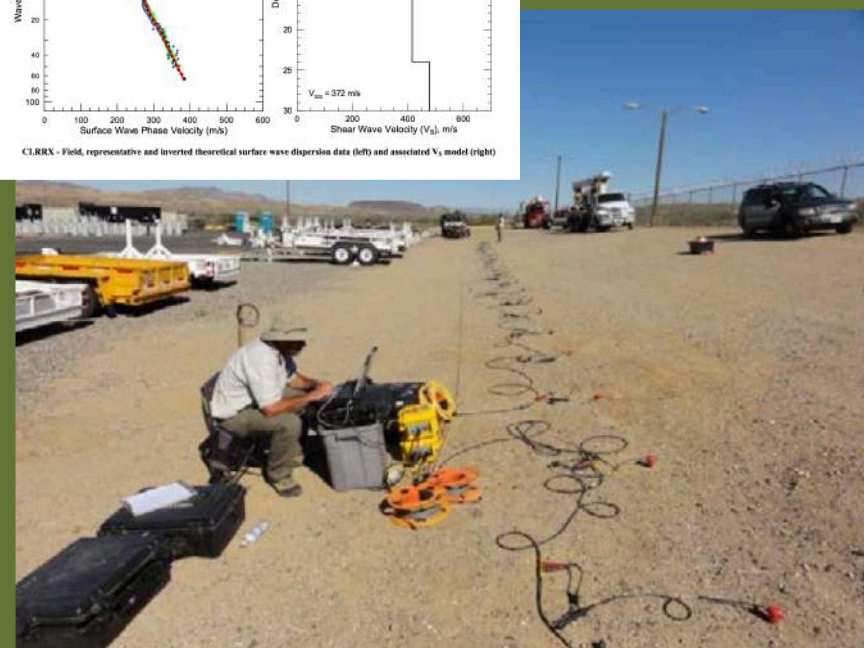
Geophysical Techniques

Invasive
(PS-suspension)

Non-invasive
(MASW)







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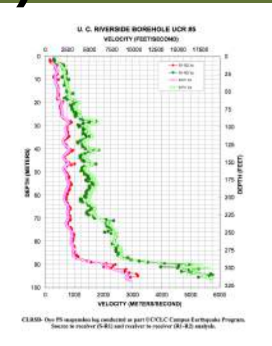
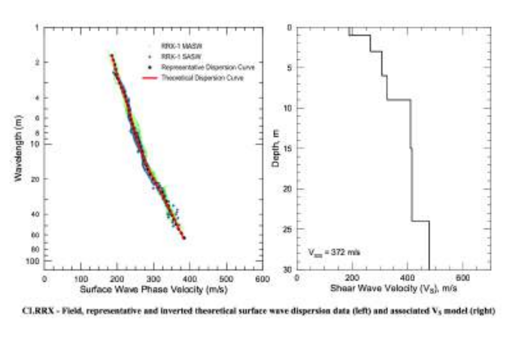
Geophysical Techniques

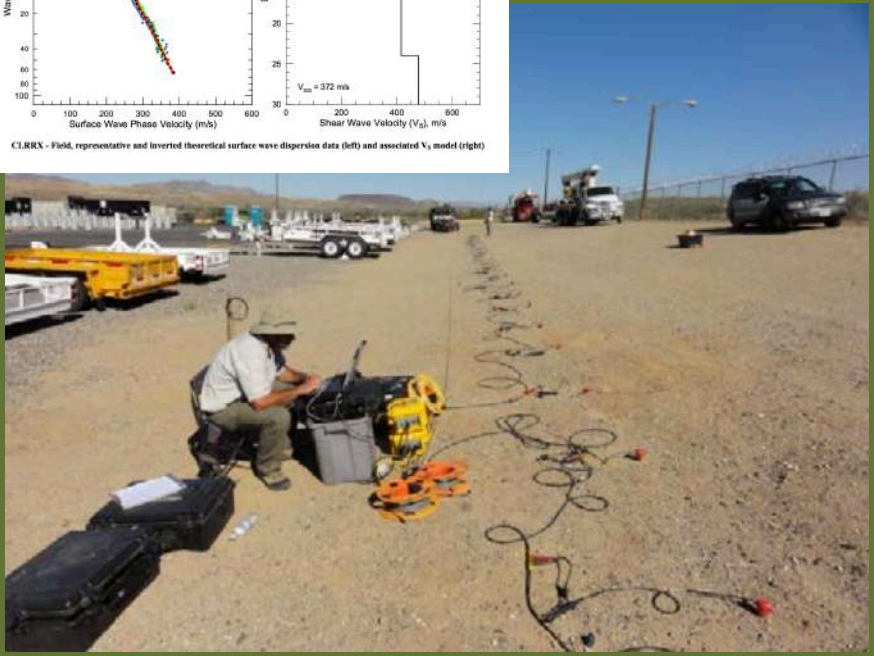
Inva$$$ive
(PS-suspension)



Non-invasive
(MASW)



C1.RRX - Field, representative and inverted theoretical surface wave dispersion data (left) and associated Vs model (right)



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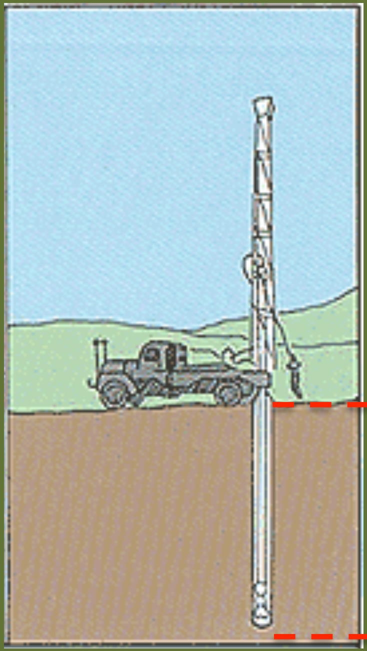
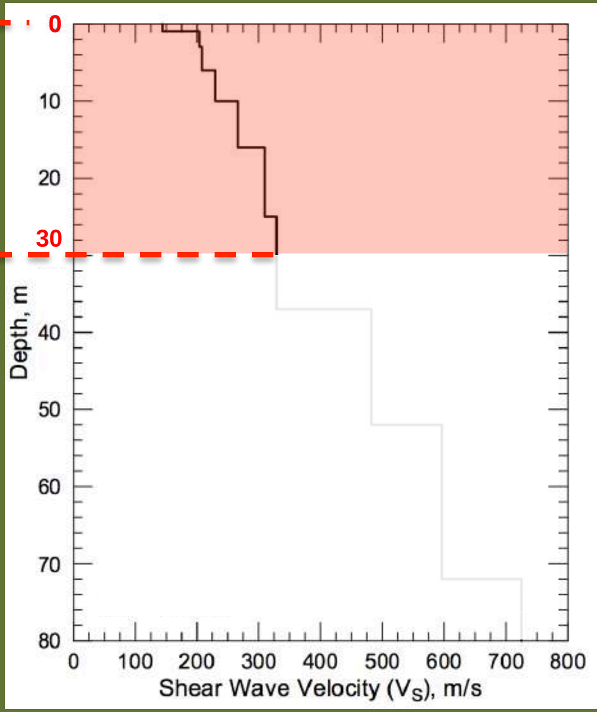
Inva$ive/Borehole Technique$

Photo Credit: Cécile Cornou



Apparently,
V_{s30} *had roots in the borehole drilling industry & this was during times of limited technology, so…*

*…~**100** feet, or **30** meters, is the depth that a drill-rig can reach in a day's work, which has direct implications related to cost and environmental factors.*



Geophysical Techniques
Non-invasive

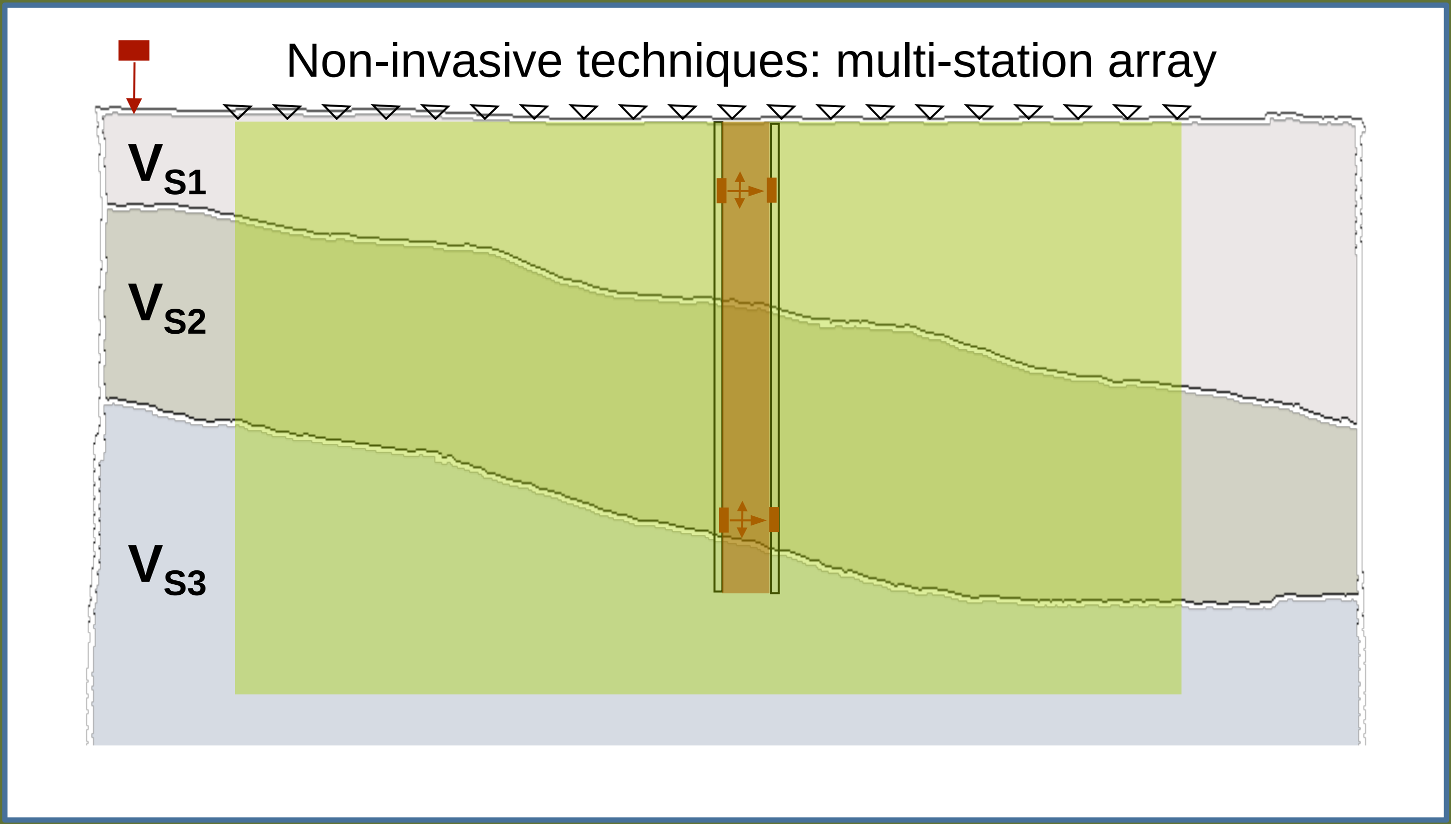


Figure Credit: Cécile Cornou

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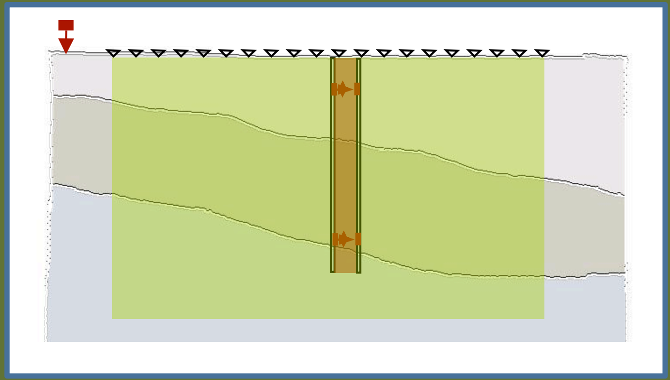
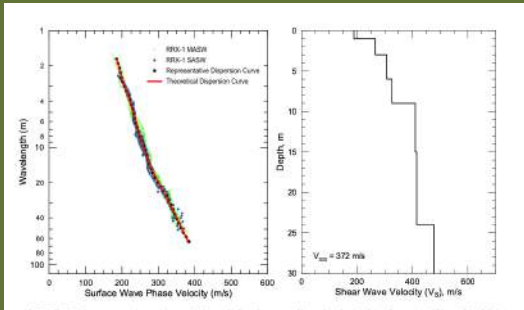
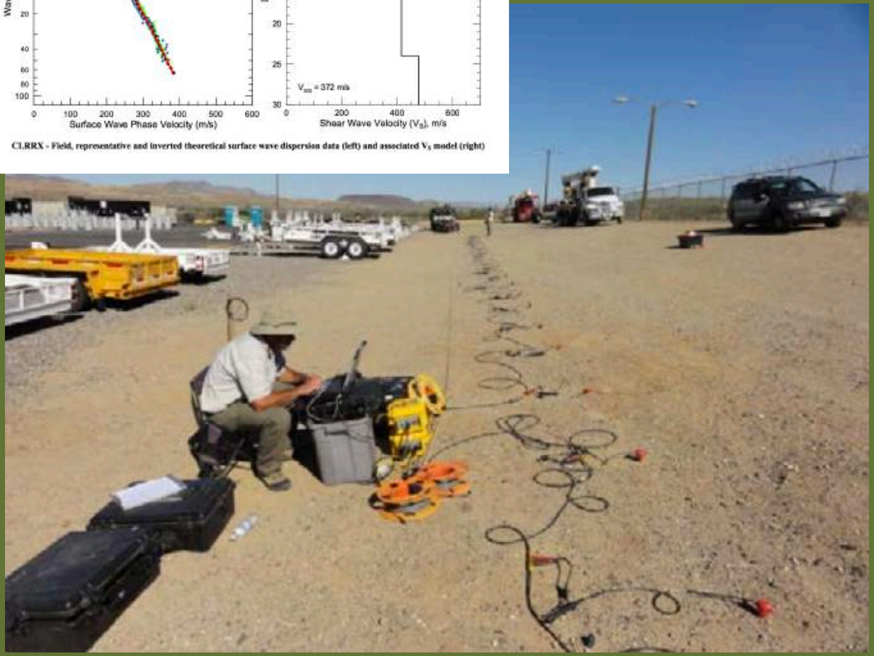
Geophysical Techniques



Non-invasive
(MASW example)



CI.RRX - Field, representative and inverted theoretical surface wave dispersion data (left) and associated V_S model (right)



- Relatively less monetary cost
- No (or minimal) environmental destruction
- Greater lateral and depth resolution despite non-unique solution to V_S profile

Non-invasive Techniques

Rayleigh Wave Processing

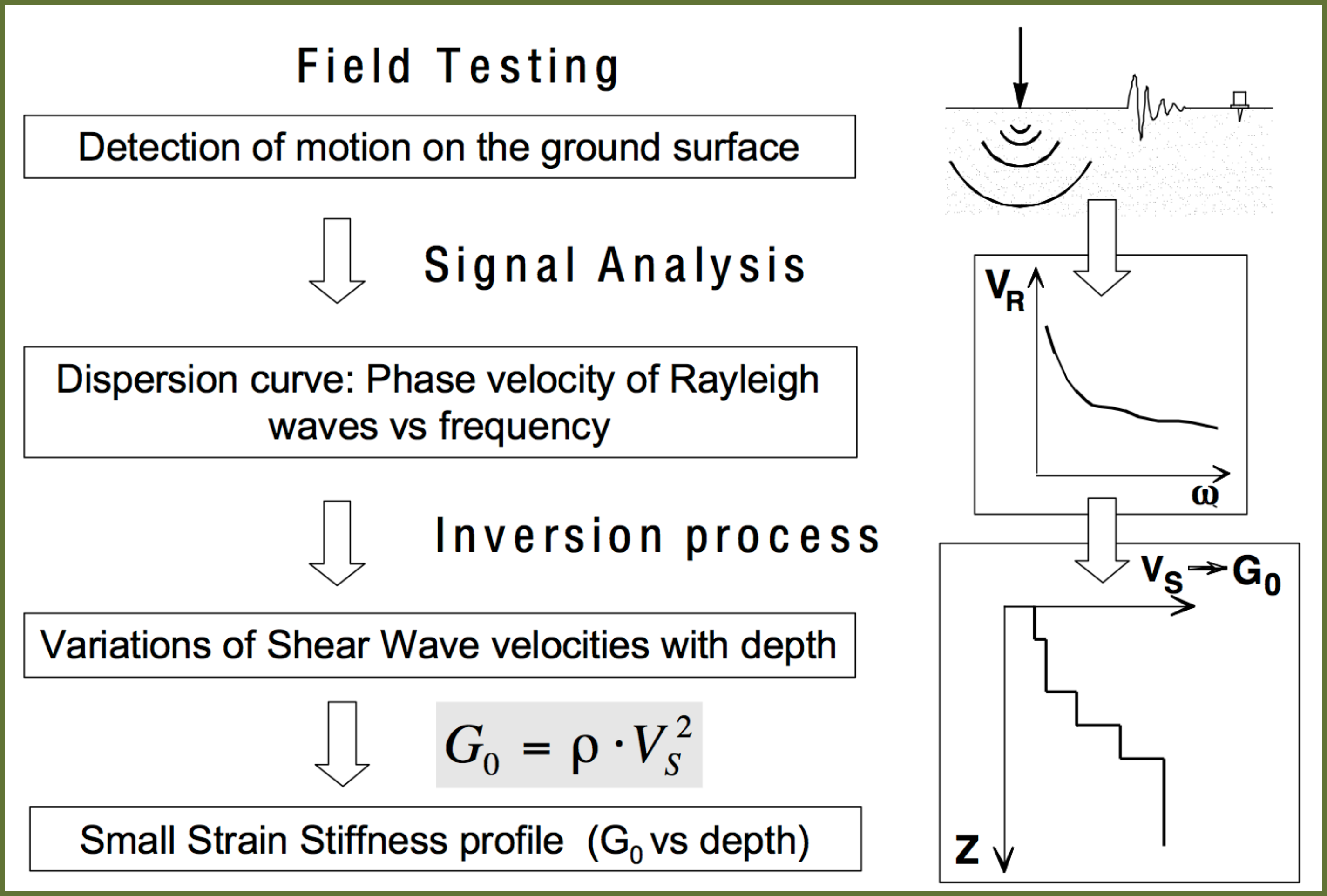
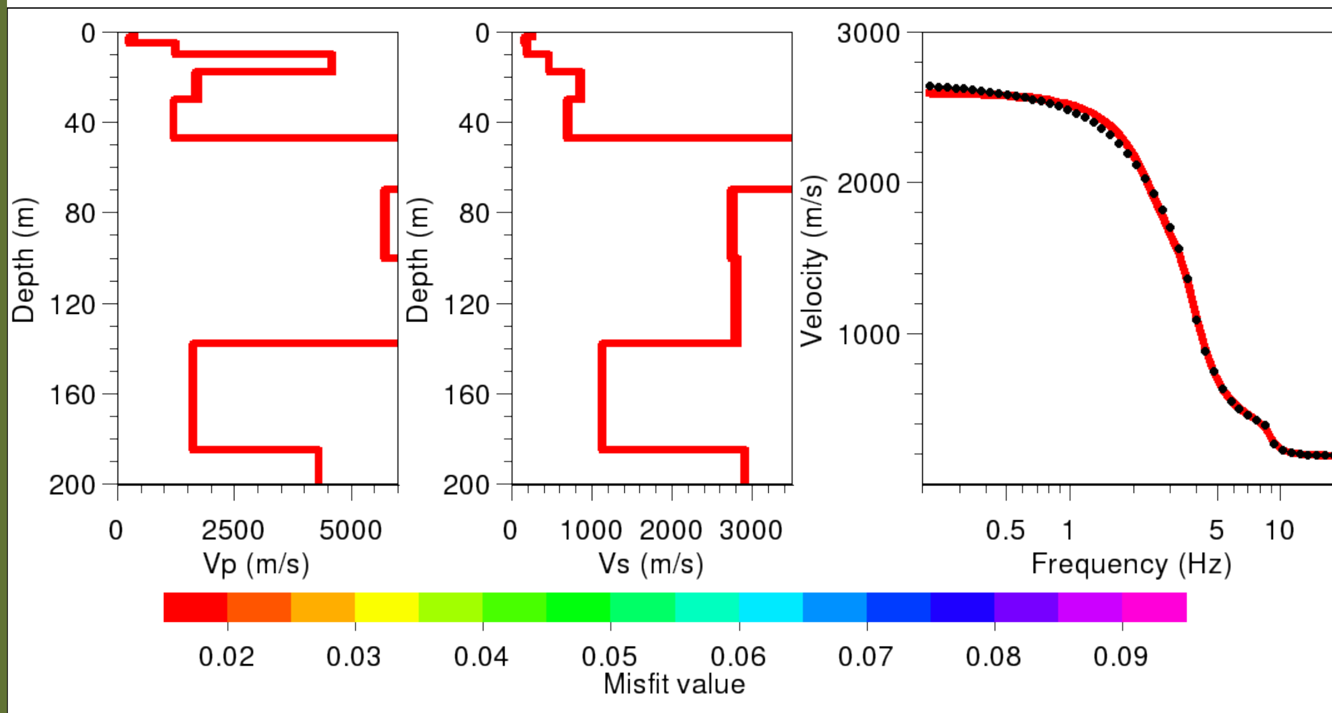


Figure Credit: Sebastiano Foti

Non-invasive Techniques

Rayleigh Wave Processing; Inversion; Pitfalls

Dangers of unconstrained least square approach surface wave inversion



USGS UNLV Using ambient vibration techniques for site characterization
February 6th-12th, 2012, Las Vegas, USA ISTerre

Figure Credit: Cécile Cornou

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Non-invasive Techniques

Rayleigh Wave Processing; Inversion; Pitfalls

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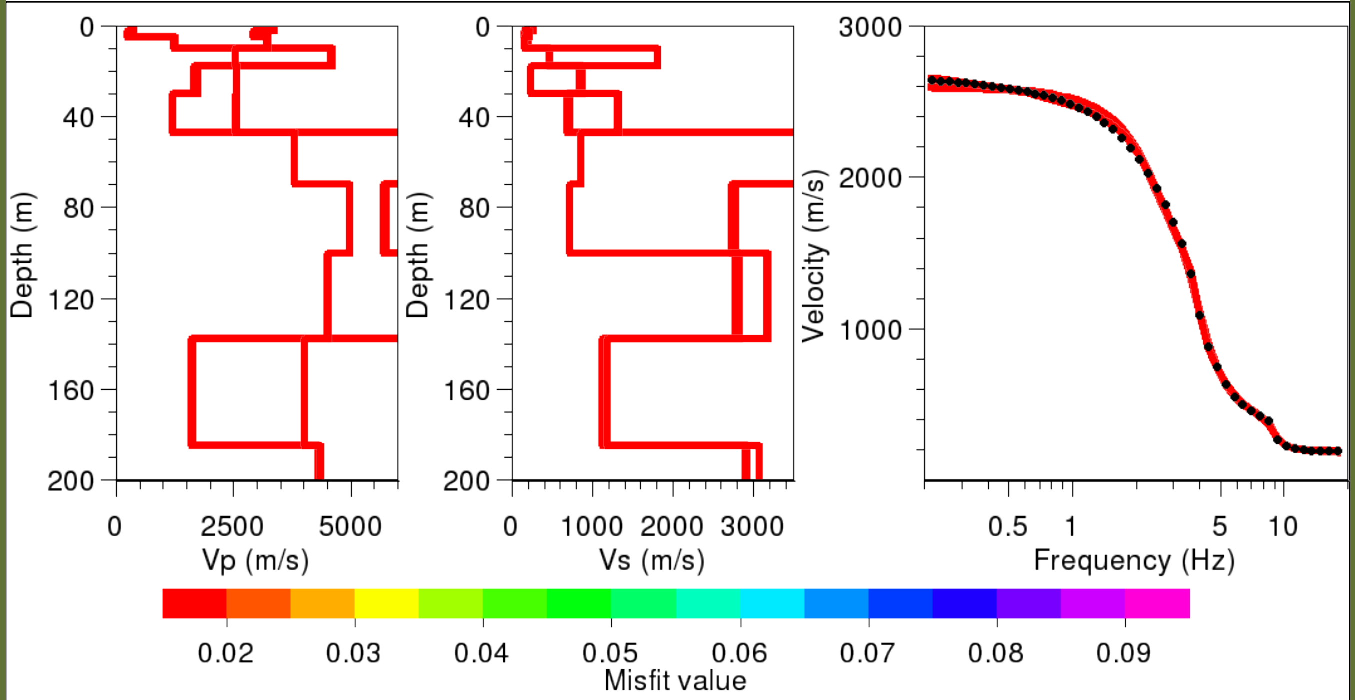

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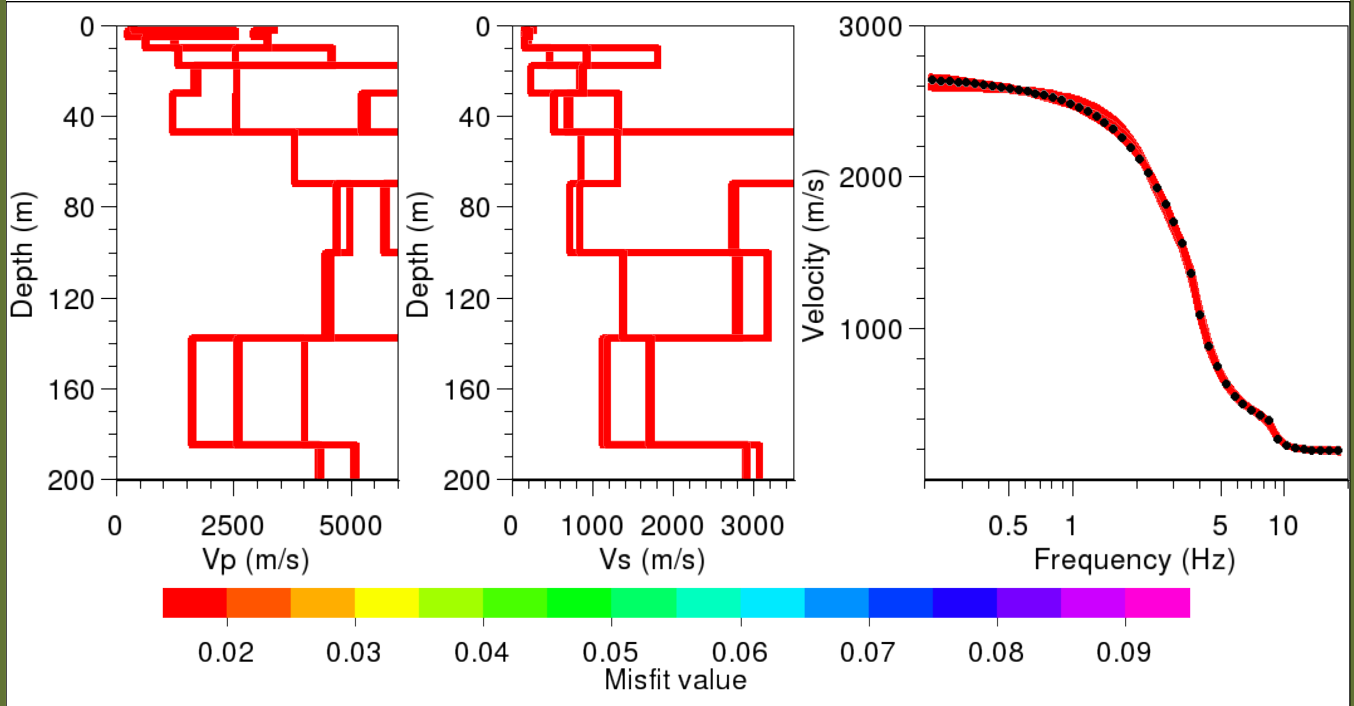

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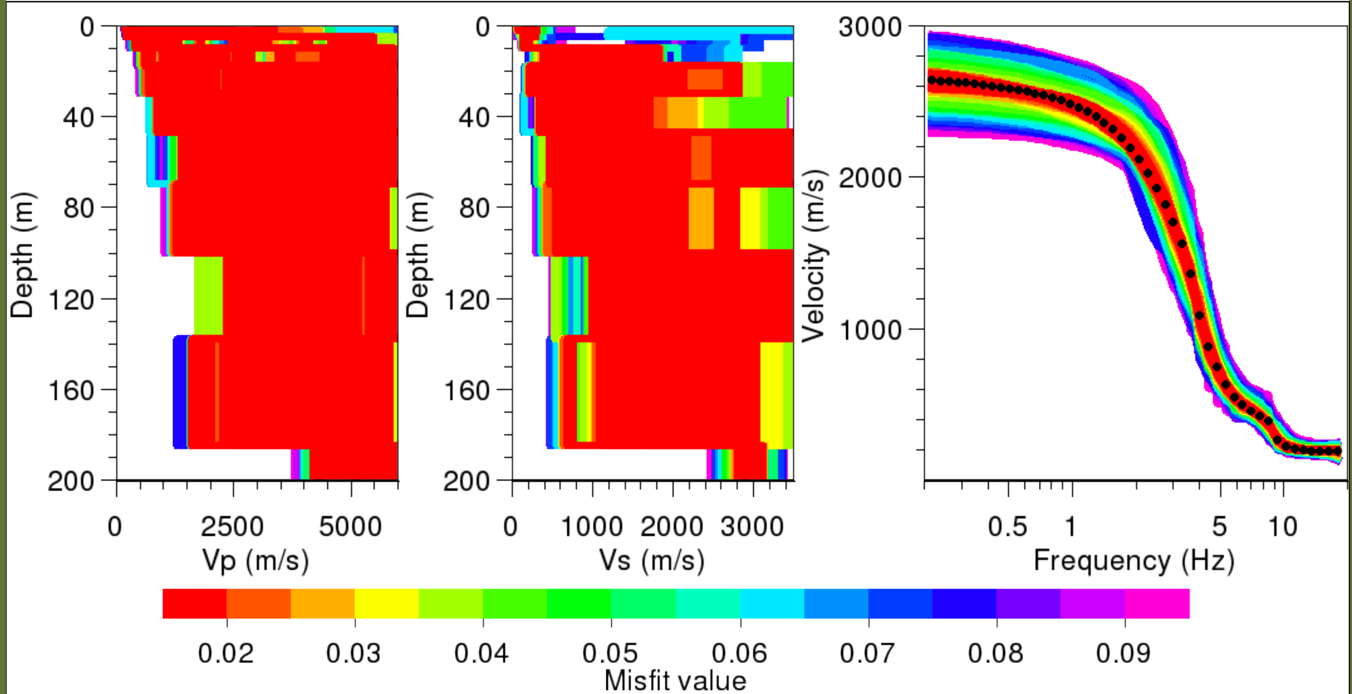

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Geophysical Techniques

Invasive and Non-invasive

- **PREVIOUS COMPARISONS:**
  - Boore (2006) in California: one site, multiple methods, multiple analysts
  - Renalier *et al*. (2009): multiple sites, multiple methods, single analyst
  - Moss (2008): multiple sites, multiple methods, review paper
  - Cornou *et al*. (2006): multiple sites, multiple methods, multiple analysists, synthetics (no real borehole measurements)
  - Cox *et al*. (2014): one site, several methods, several analysists, no borehole measurements

- **SUMMARY:**
  - **Low variability in dispersion estimates**
  - **Large variability in inverted shear-wave velocity profiles**
  - **Low variability in V_{S30} estimates**

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2009
American Recovery & Reinvestment Act

http://www.recovery.gov/Pages/default.aspx

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Open-File Report 2013–1102

ARRA-Funded V_{S30} Measurements Using Multi-Technique Approach at Strong-Motion Stations in California and Central-Eastern United States

By Alan Yong, Antony Martin, Kenneth Stokoe, and John Diehl

Abstract

Funded by the 2009 American Recovery and Reinvestment Act (ARRA), we conducted geophysical site characterizations at 191 strong-motion stations: 187 in California and 4 in the Central-Eastern United States (CEUS). The geophysical methods used at each site included passive and active surface-wave and body-wave techniques. Multiple techniques were used at most sites, with the goal of robustly determining V_S (shear-wave velocity) profiles and V_{S30} (the time-averaged shear-wave velocity in the upper 30 meters depth). These techniques included: horizontal-to-vertical spectral ratio (HVSR), two-dimensional (2-D) array microtremor (AM), refraction microtremor (ReMi™), spectral analysis of surface wave (SASW), multi-channel analysis of surface waves (Rayleigh wave: MAS_RW; and Love wave: MAS_LW), and compressional- and shear-wave refraction. Of the selected sites, 47 percent have crystalline, volcanic, or sedimentary rock at the surface or at relatively shallow depth, and 53 percent are of Quaternary sediments located in either rural or urban environments. Calculated values of V_{S30} span almost the full range of the National Earthquake Hazards Reduction Program (NEHRP) Site Classes, from D (stiff soils) to B (rock). The NEHRP Site Classes based on V_{S30} range from being consistent with the Class expected from analysis of surficial geology, to being one or two Site Classes below expected. In a few cases where differences between the observed and expected Site Class occurred, it was the consequence of inaccurate or coarse geologic mapping, as well as considerable degradation of the near-surface rock. Additionally, several sites mapped as rock have Site Class D (stiff soil) velocities, which is due to the extensive weathering of the surficial rock.

First posted June 27, 2013

- **Report** PDF, text (65 pages, 4.8 megabytes)
- **Appendix A** PDF, site reports (2,160 pages, 278 megabytes)
- **Data repository** folder, one zip archive for each site as well as a single file that contains all of the data in a single zip archive (190 files, 106 gigabytes total)

For additional information:
Contact Information, Pasadena, Calif.
Field Office—Earthquake Science Center
U.S. Geological Survey
525 South Wilson Ave.
Pasadena, CA 91106-3212
http://earthquake.usgs.gov/

Suggested citation:

Yong, A., Martin, A., Stokoe, K., and Diehl, J., 2013, ARRA-funded V_{S30} measurements using multi-technique approach at strong-motion stations in California and central-eastern United States: U.S. Geological Survey Open-File Report 2013–1102, 60 p. and data files, http://pubs.usgs.gov/of/2013/1102/.

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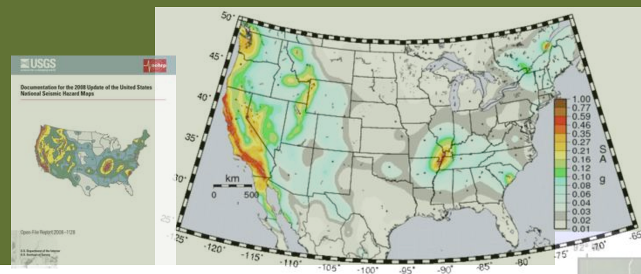

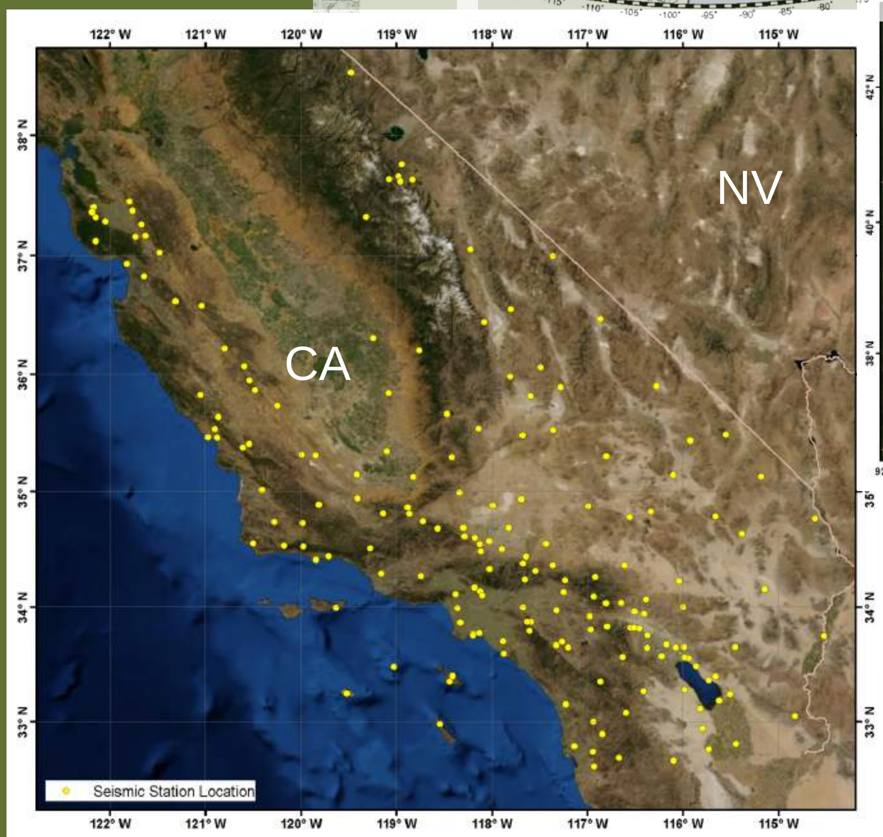

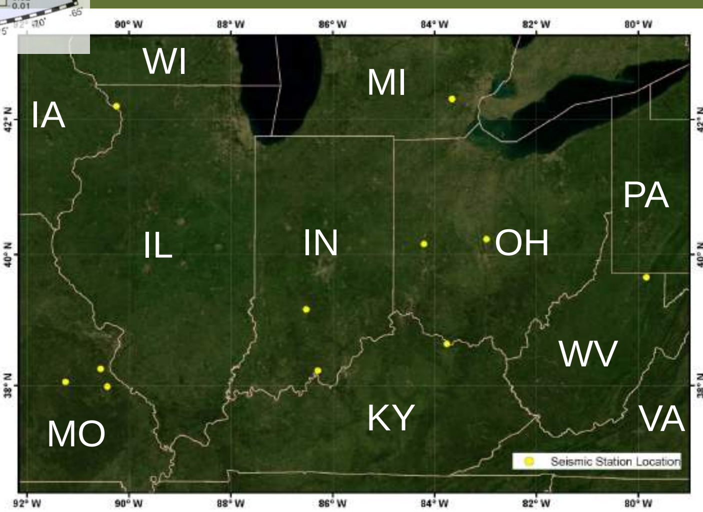

4 (12) SM sites in CEUS

185 SM sites
in CA

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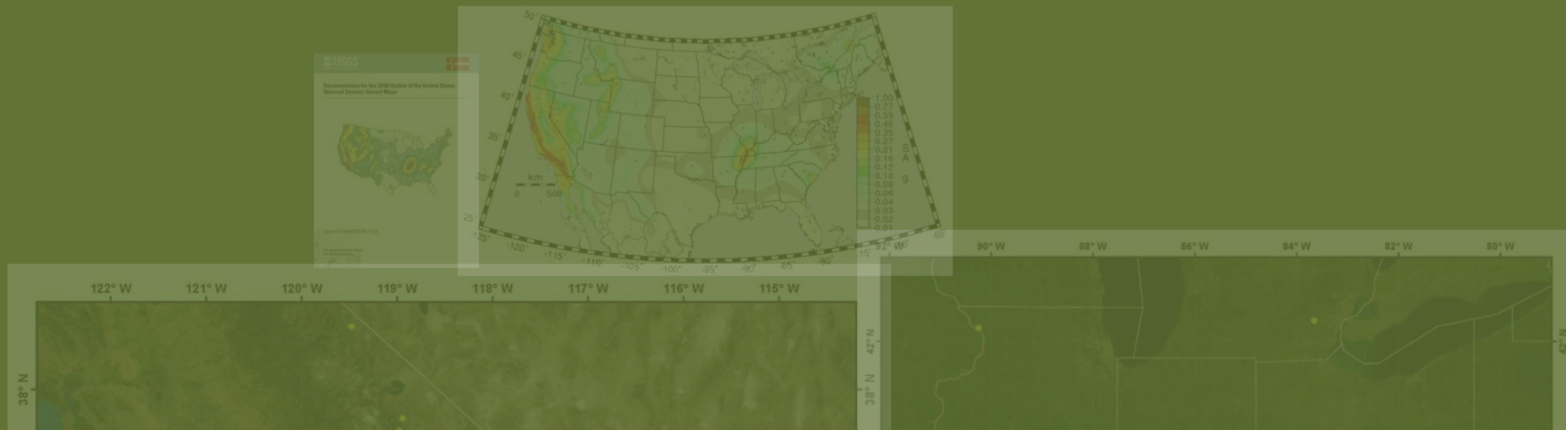
ARRA: Strong Motion Station Site Selection



Sites	Seismographic Networks	
130	SCSN -	Southern California Seismographic Network
30	NCSN -	Northern California Seismographic Network
25	CSMIP -	California Strong Motion Instrumentation Program
4 (12)	CERI -	Center for Earthquake Research Institute (Central U.S.)

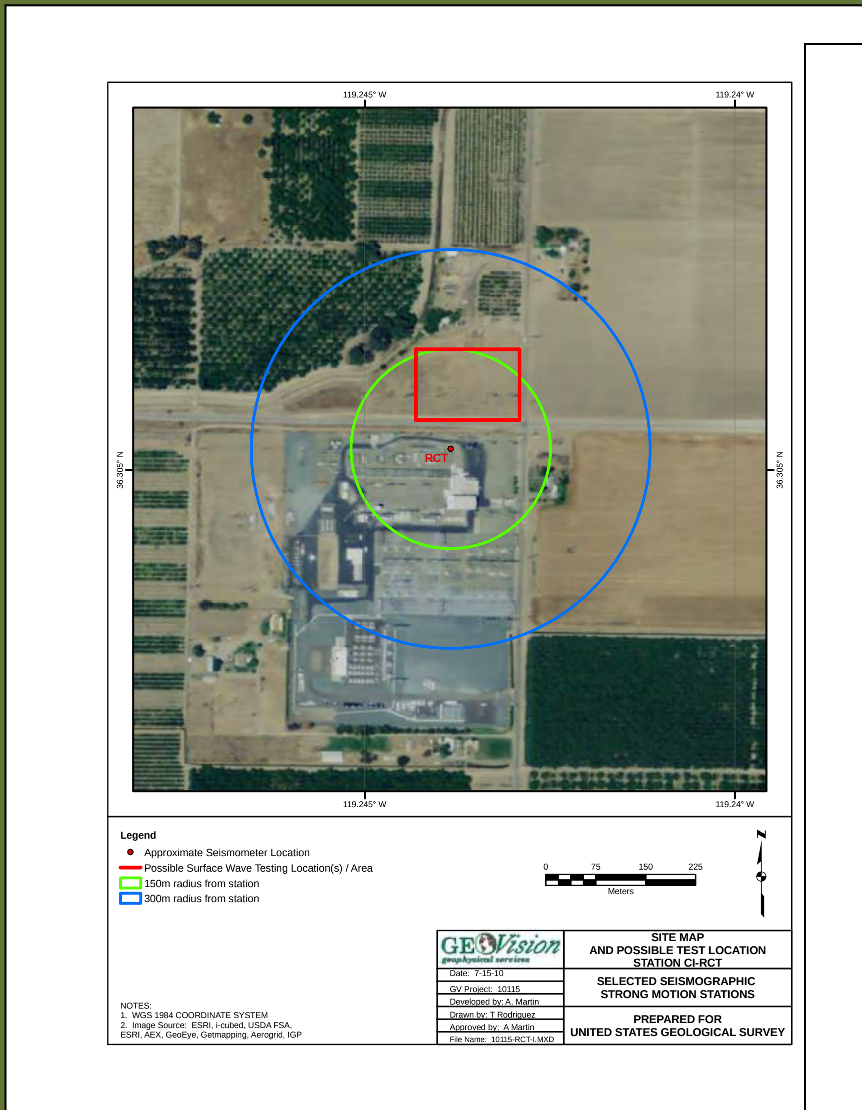
189 (197) Total Sites

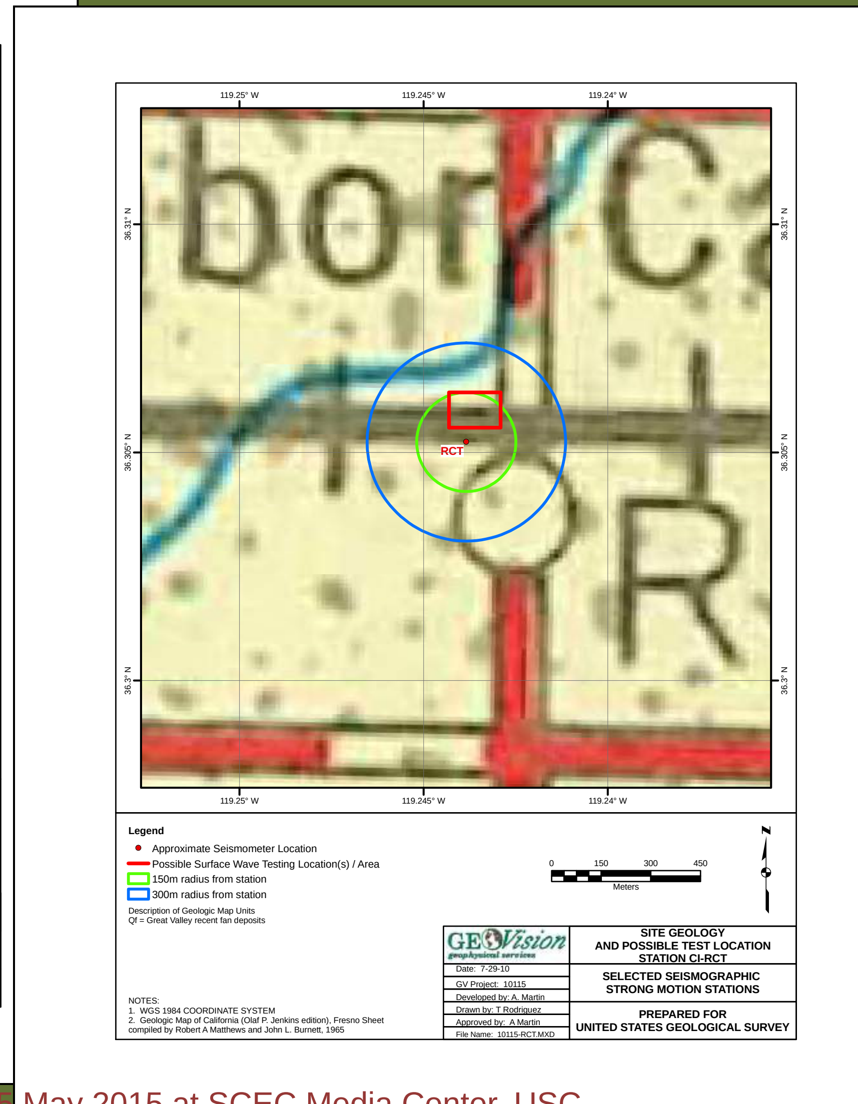
ARRA: Geophysical Techniques Based on Site Conditions

Types of Site Conditions	Geophysical Techniques					
			Active Surface Wave		Passive Surface Wave	
	H/V Spectral Ratio	P-Wave Seismic Refraction	SASW	MASW	Array Microtremor	ReMi ™
Rock/Shallow Rock Sites	•	•	•	•		
Urban Soil Sites	•			•	•	•
Semi Urban Soil Sites	•		•	•	•	•
Rural Soil Sites	•		•			

ARRA: Proximity of Survey to SM Instruments
Pre-survey Reports & Approvals

Yong *et al*. (2013; USGS OFR 2013-1102)





Research Topics
- Characterizing Faults
- Early Warning
- Crustal Deformation
- Earthquake Processes
- Ground Failure
- Ground Motion
- Hazard & Risk
- Improving Monitoring
- Induced Earthquakes

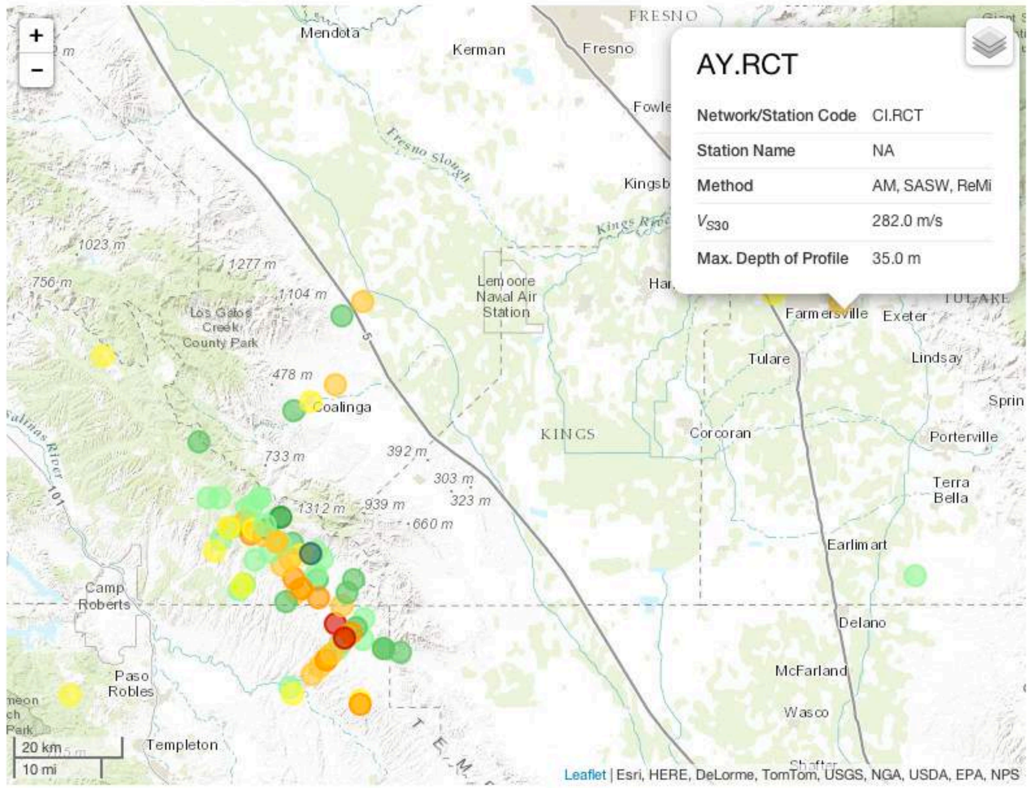
Regional Science Activities
- Alaska Science Center
- Seattle Field Office
- Earthquake Science Center
- Pasadena Field Office
- Geologic Hazards Science Center

External Research Support

Software

A Compilation of V_{S30} Values in the United States

V_{S30}, the time-averaged shear-wave velocity (V_S) in the upper 30 meters, is a key index adopted by the earthquake engineering community to account for seismic site conditions. USGS has compiled measured V_{S30} funded by the USGS and other governmental agencies for 2997 sites in the United States.



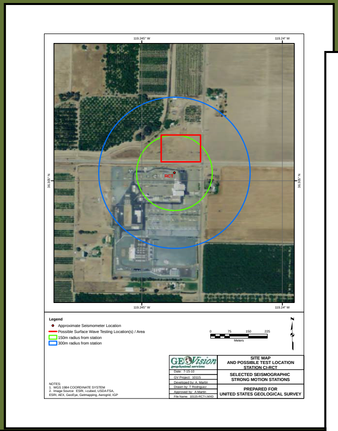
V_{S30} Ranges (m/s)

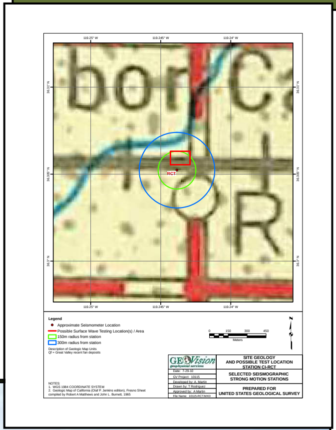
No value · < 180 · 180–240 · 240–300 · 300–360 · 360–490 · 490–620 · 620–760 · > 760

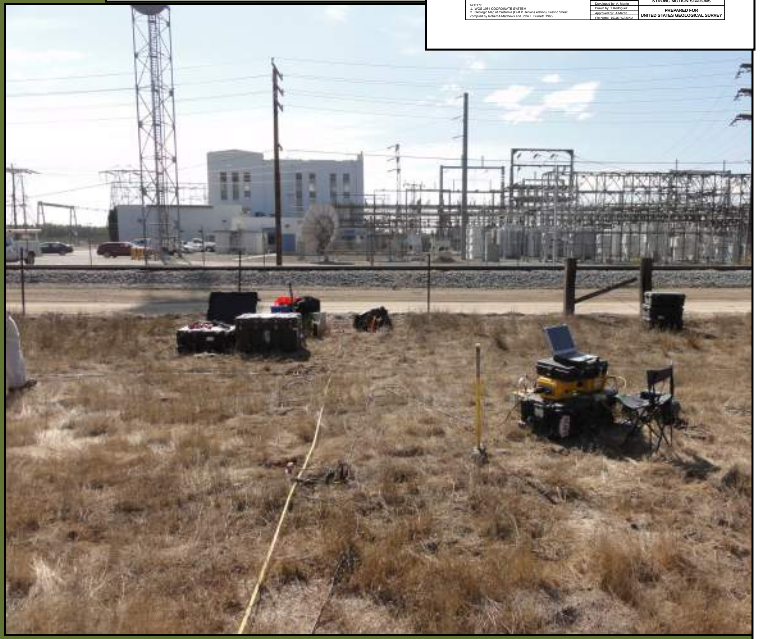
Download V_{S30} Data (.csv format)

ARRA: Non-invasive Techniques

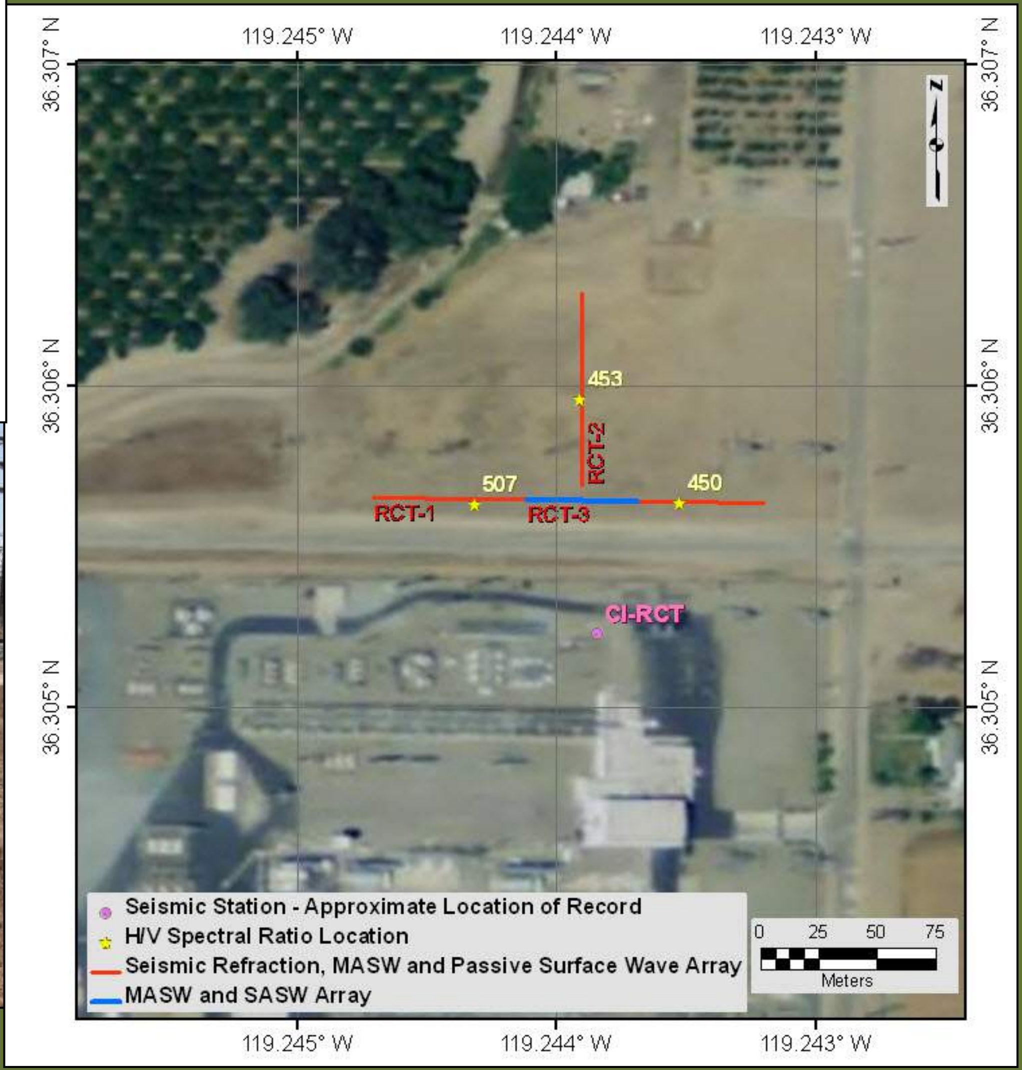
CI.RCT (V_S Model from Multi-technique Approach)







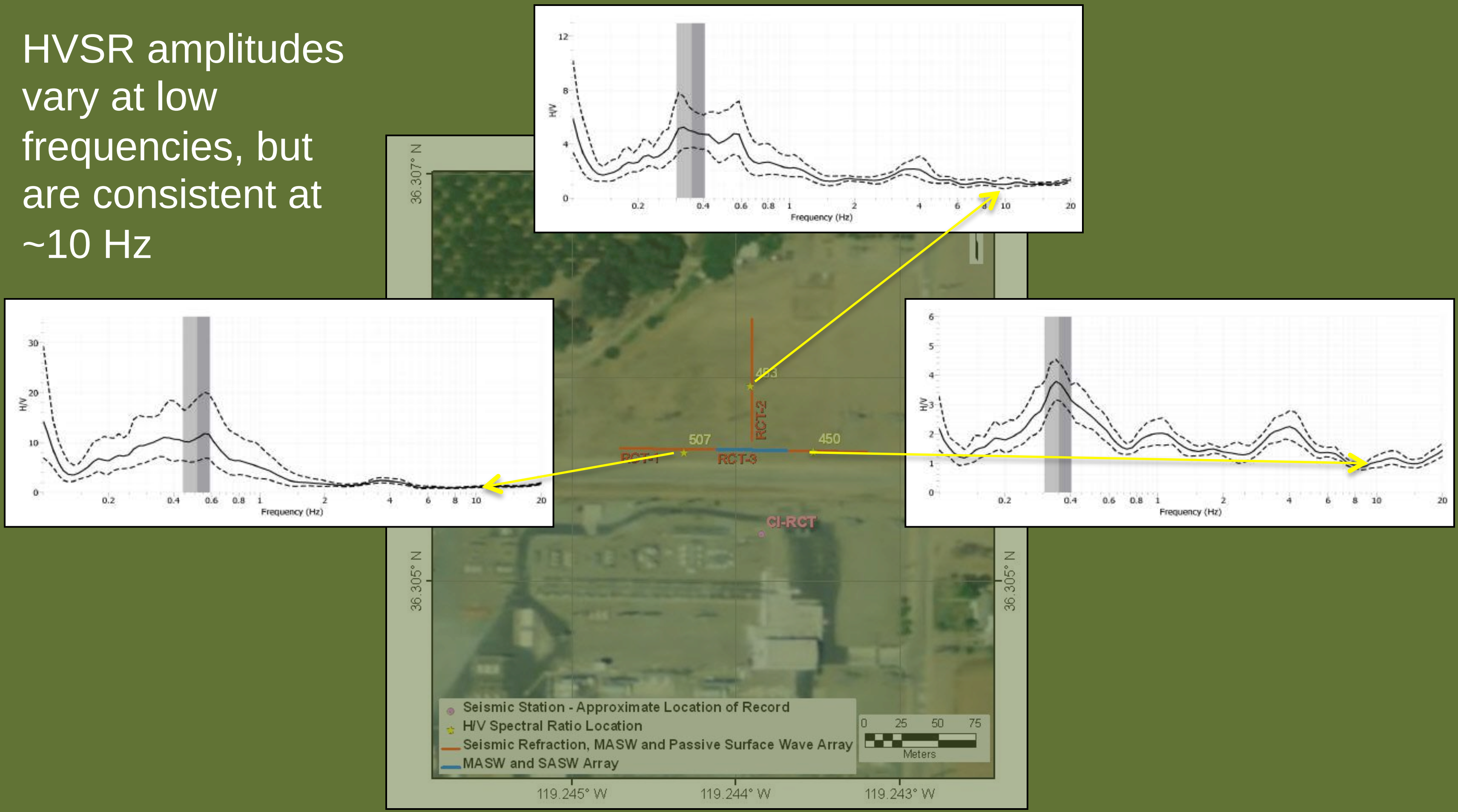
Yong *et al*. (2013; USGS OFR 2013-1102)



ARRA: Non-invasive Techniques

CI.RCT (V_S Model from Multi-technique Approach)

HVSR amplitudes vary at low frequencies, but are consistent at ~10 Hz



Yong *et al*. (2013; USGS OFR 2013-1102)

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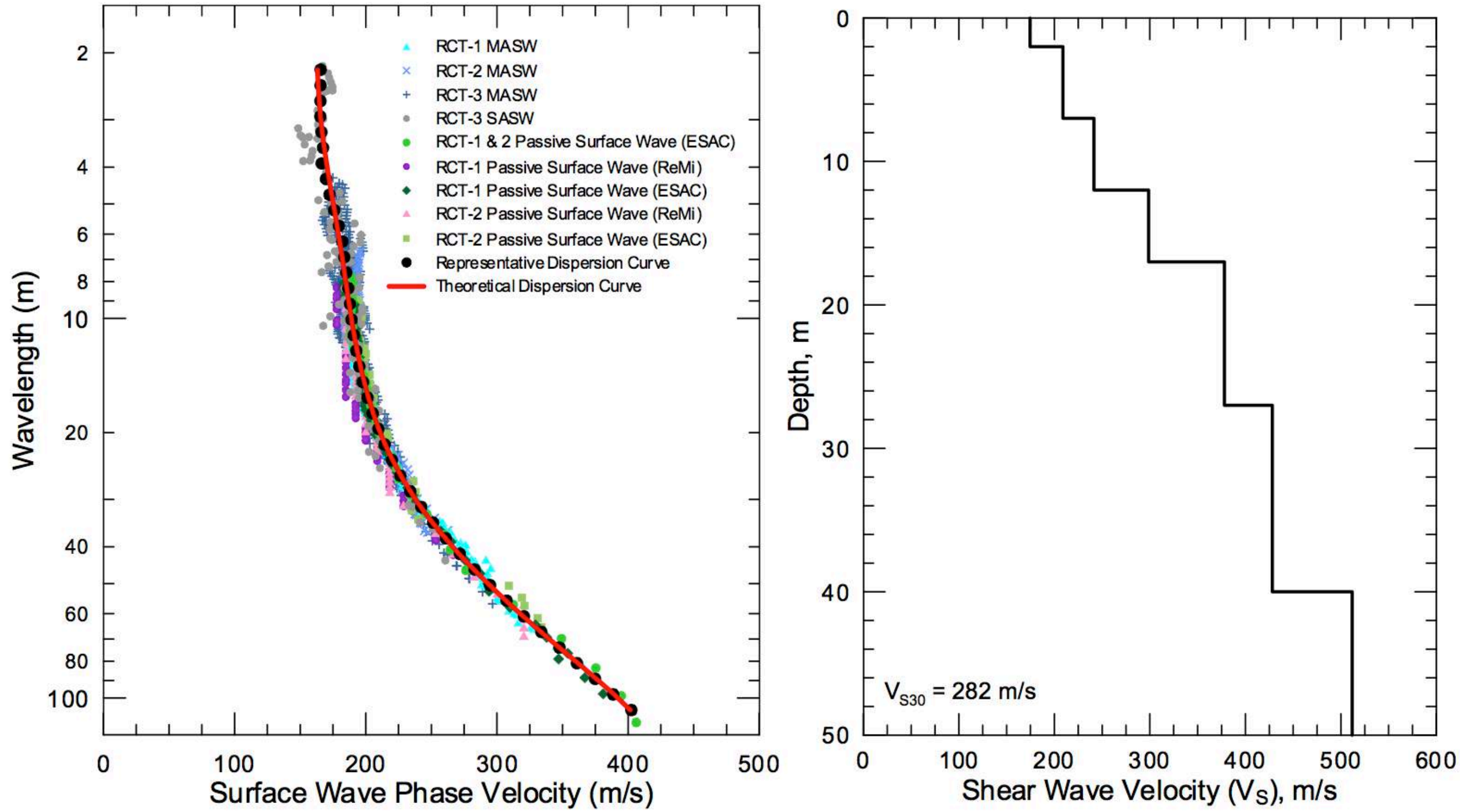
ARRA: Non-invasive Techniques

CI.RCT (V_S Model from Multi-technique Approach)



CI.RCT - Field, representative and inverted theoretical surface wave dispersion data (left) and associated V_S model (right)

Yong *et al*. (2013; USGS OFR 2013-1102)

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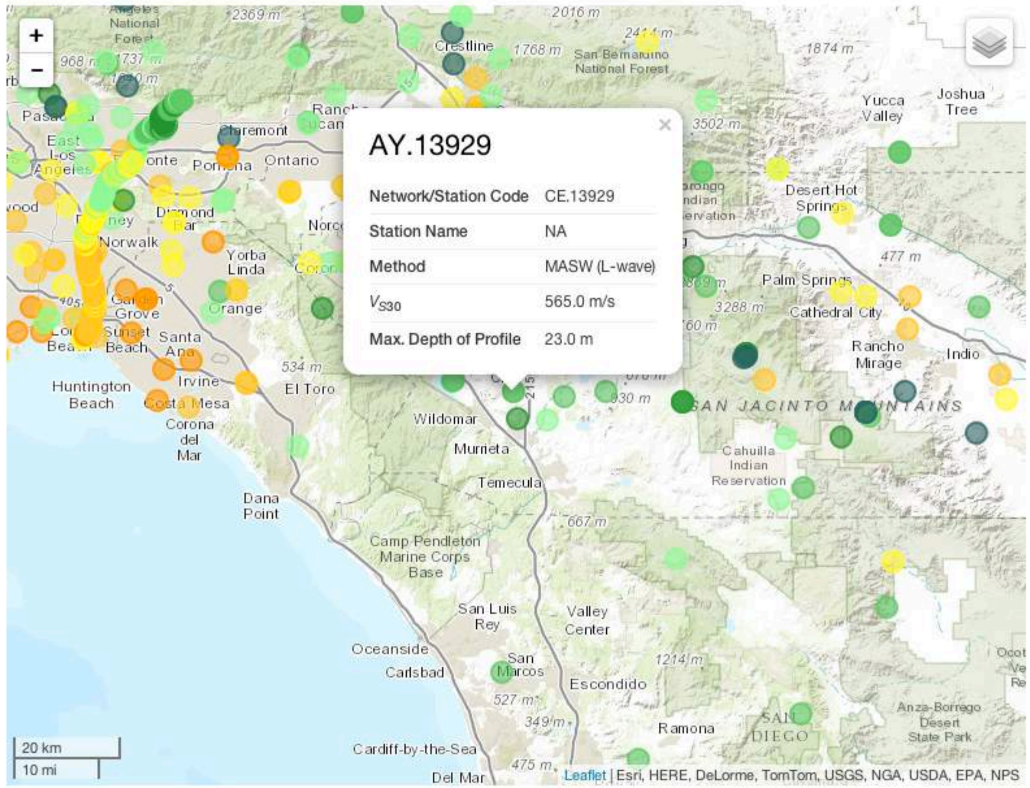

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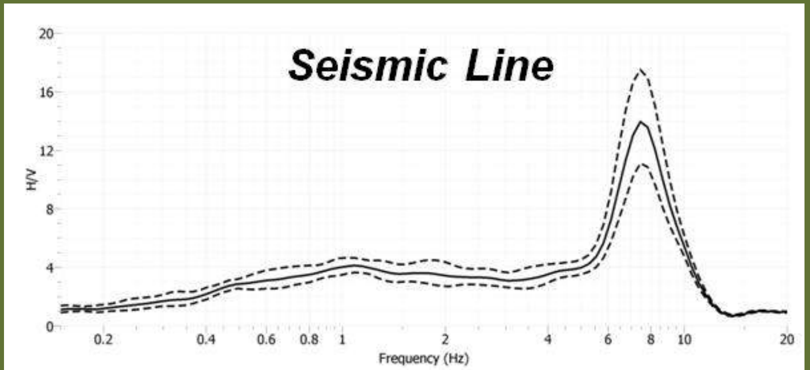
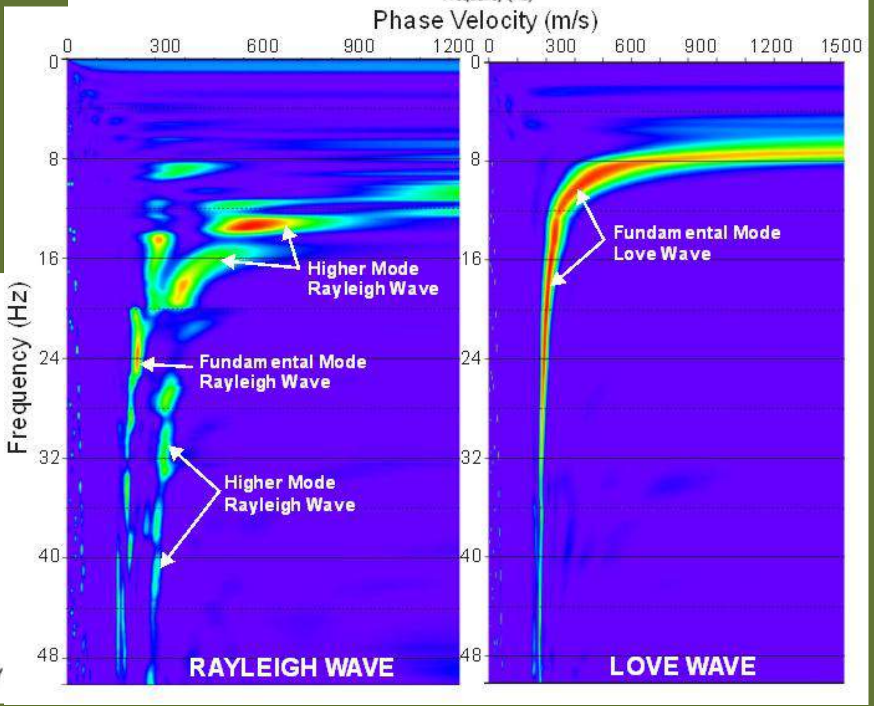
ARRA: Non-invasive Techniques

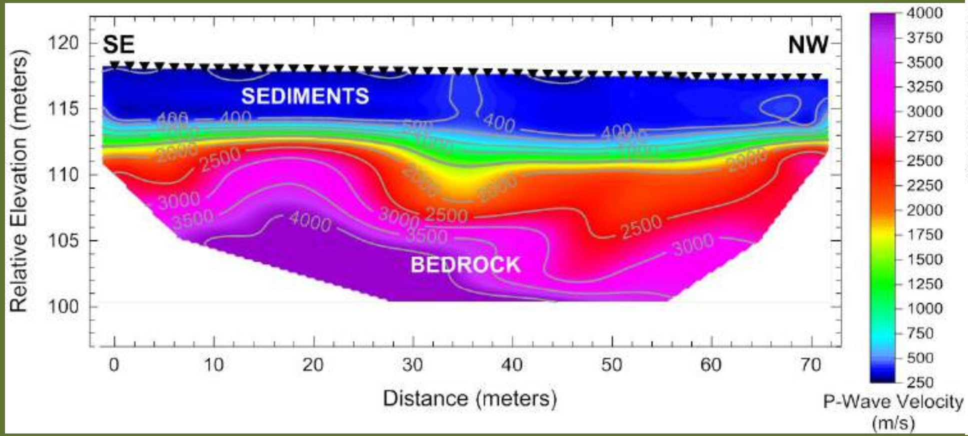
CE.13929 (V_S Model from Multi-technique Approach)

- Shallow rock site according to P-wave seismic refraction model and high frequency HVSR peak (7.5 Hz).
- First site in the ARRA project where MAS_RW ineffective but MAS_LW effective.
    - Complex Rayleigh wave propagation.
    - Fundamental mode Love wave is very clear.

Yong *et al*. (2013; USGS OFR 2013-1102);
Martin *et al*. (2014; Proceedings of 10th NCEE Conf.

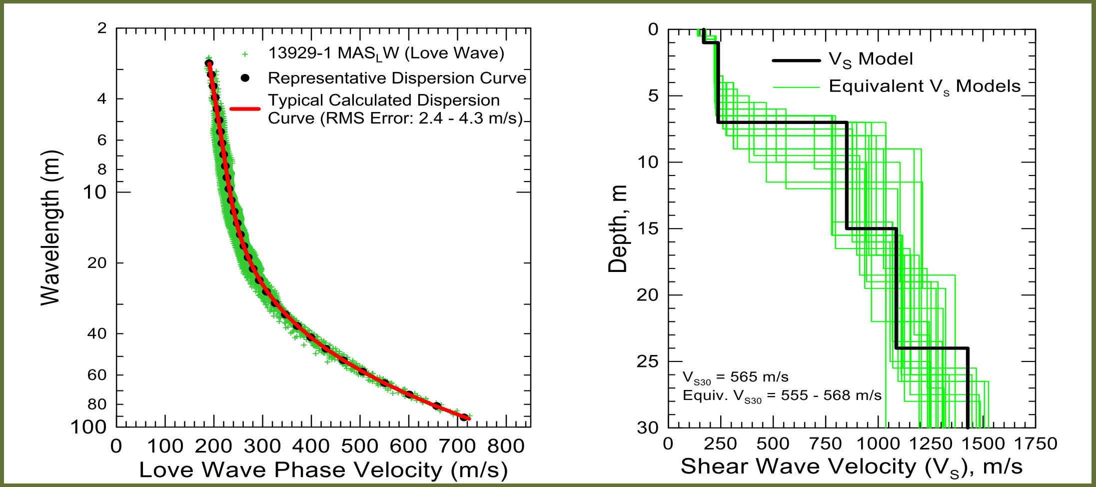






ARRA: Non-invasive Techniques

CE.13929 (V_S Model from Love Wave Dispersion Data)



Yong *et al*. (2013; USGS OFR 2013-1102);
Martin *et al*. (2014; Proceedings of 10th NCEE Conf.

- Multiple V_S models developed to demonstrate non-uniqueness
- V_{S30} range: 555 to 568 m/s (not sensitive to non-uniqueness)
- V_S model with shallower bedrock (black profile) is most consistent with P-wave seismic reflection model.

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Summary/Remarks

Summary:

- USGS focus/efforts thus far has been about V_{S30}, not so much about V_S profiles as driven by GMPEs, ShakeMaps, etc.
- Non-invasive (surface-wave based) V_S profiles can vary substantially (non-uniqueness in inversion) for a site, thus critical to site specific physics-based models. Resultant site V_{S30}, however, does not vary substantially, thus V_{S30} does not effect regional-scale applications, e.g., GMPEs.
- Invasive borehole techniques are too expen$ive/environmentally-prohibitive and need *a priori* site info (sampling interval) to be effective.
- Non-invasive techniques are relatively inexpensive (field) and need *a priori* site info (constrain inversion), but requires expen$e ("brain power"- C. Cornou, 2015; pers. comm.) to process/analyze (inversion) records.
- Non-invasive multi-technique approaches can reduce uncertainty from dispersion pick phase, but more importantly, from inversion process by applying complementary techniques to help select best V_S profiles.

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Challenges → Future Work:

- Currently, there are no centralized V_s profile database → use USGS V_{s30} compilation/ website as framework; USGS/PEER/COSMOS V_S Profile Database Proto-Working Group to meet 27 May 2015.

- Currently, not all S. CA strong motions stations have V_S profiles → characterize station site conditions (V_S) using non-invasive robust multi-techniques approach and non-station sites using less robust measured approaches (V_{R40}, HVSR, etc.) calibrated against nearby station measurements.

End

Thank You

Discussions