



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

Outline:

- U.S. Compilation of $V_{s30} \rightarrow V_s$ 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.)

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

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



A Compilation of V_{s30} in the United States

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Poster No. 13


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Pasadena and Menlo Park, California, and Golden, Colorado
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Abstract

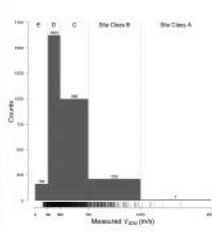
V_{s30} , the time-averaged shear-wave velocity (V_s) in the upper 30 meters, is a key index adopted by the earthquake engineering community to account for seismic site conditions. V_{s30} is typically based on geophysical measurements of V_s at sites of interest. Due to cost considerations, as well as logistical and environmental concerns, V_{s30} data have often been sparse or not readily available. To help remedy this situation, the USGS has compiled V_{s30} results obtained by studies funded by the USGS and other governmental agencies, and plans to make the data openly accessible. Thus far, V_{s30} data have been compiled for approximately 3,000 sites in the U.S., along with metadata (site name, coordinates, maximum depth of investigation, station, etc.) for each site. Data were predominantly collected from government-sponsored reports, websites and scientific/engineering journals. Most of the data in our V_{s30} compilation originated from publications directly reported by field investigators. A smaller subset (~20%) of V_{s30} values was previously compiled by the USGS or other research institutions. Whenever possible, V_{s30} values originating from these earlier compilations were crosschecked against published reports. V_{s30} values, based on downhole and/or surface geophysical techniques, are represented in our V_{s30} compilation. Most of the data reflect V_{s30} in the western contiguous U.S. (2,141), while 796 V_{s30} values were compiled for the central-eastern U.S. region; 72 sites with V_{s30} values were also compiled for Alaska (15), Hawaii (30) and Puerto Rico (27). A prototype interactive map, employing Leaflet®, Java, Script libraries and maps from MapQuest® and OpenStreetMap®, has been developed to assist the data and is expected to be the main USGS web portal for accessing V_{s30} data. An option to download the complete V_{s30} compilation will also be available on the USGS website.


Right: Quick Response Code (QR) for direct link to the USGS V_{s30} Compilation website





Right: Profile of downloaded V_{s30} distribution. Options to download data by state, by depth, by data type, by station, or by station type. The download link is provided for each option.





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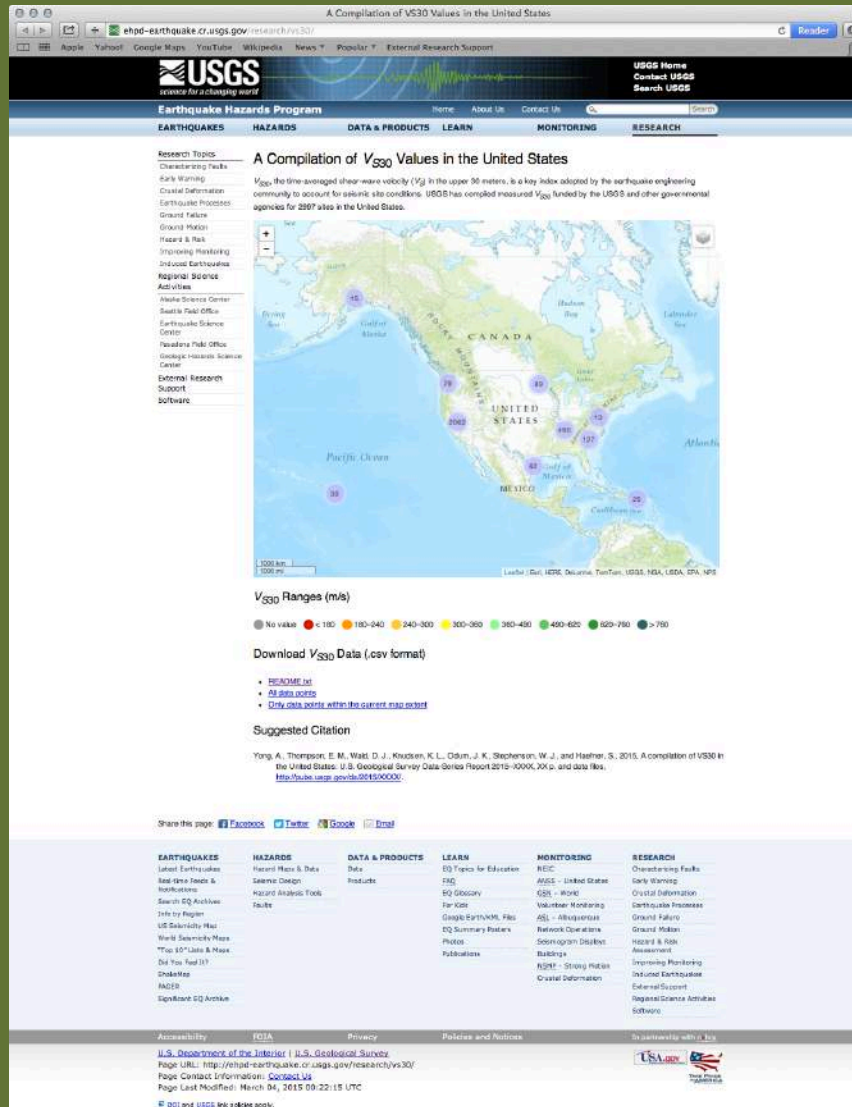
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<http://earthquake.usgs.gov/research/vs30/>

USGS V_{s30} Compilation for U.S.

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



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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 V_{S30} 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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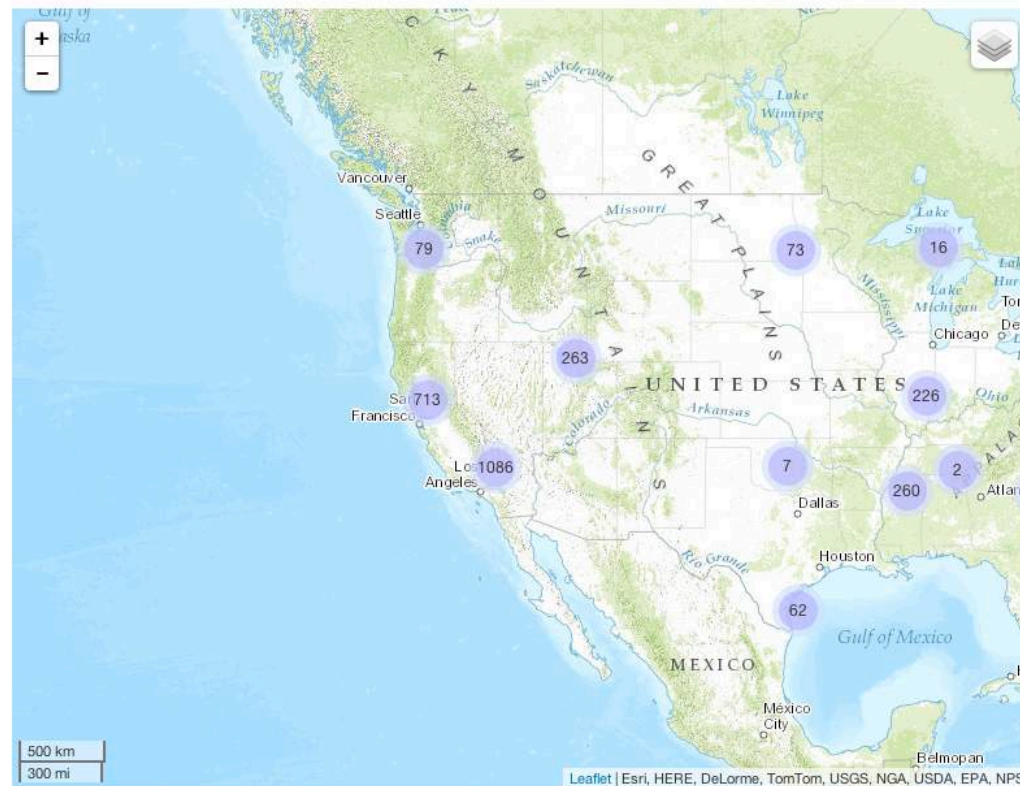
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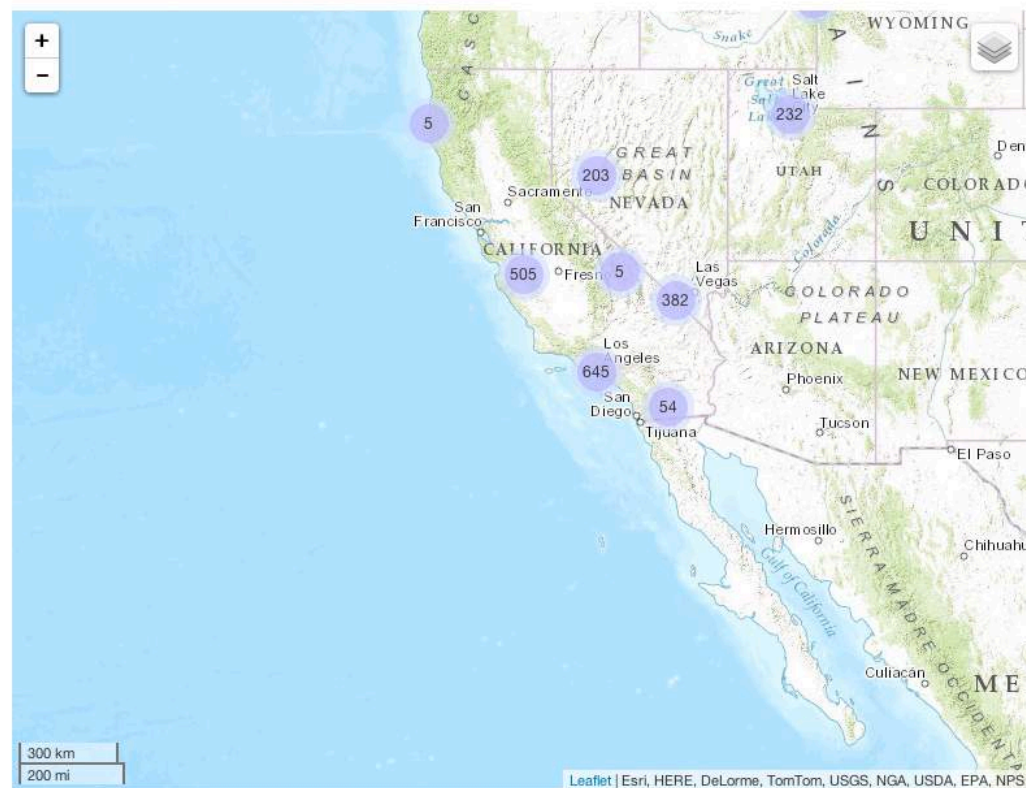
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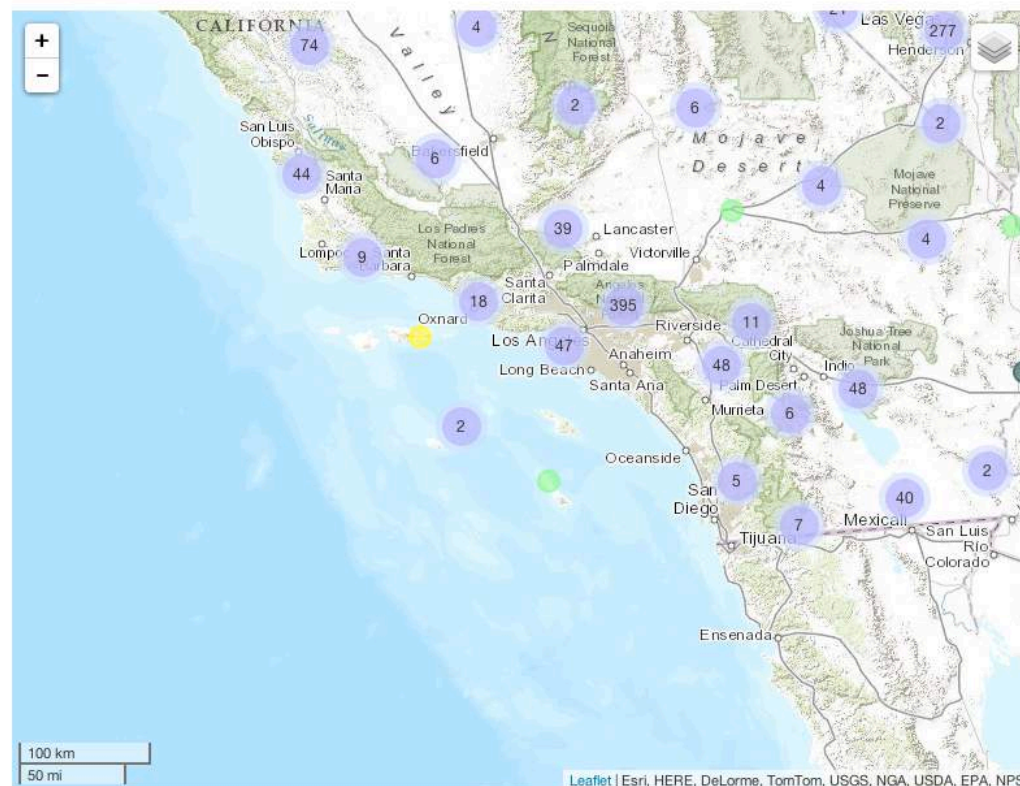
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VS30 Ranges (m/s)

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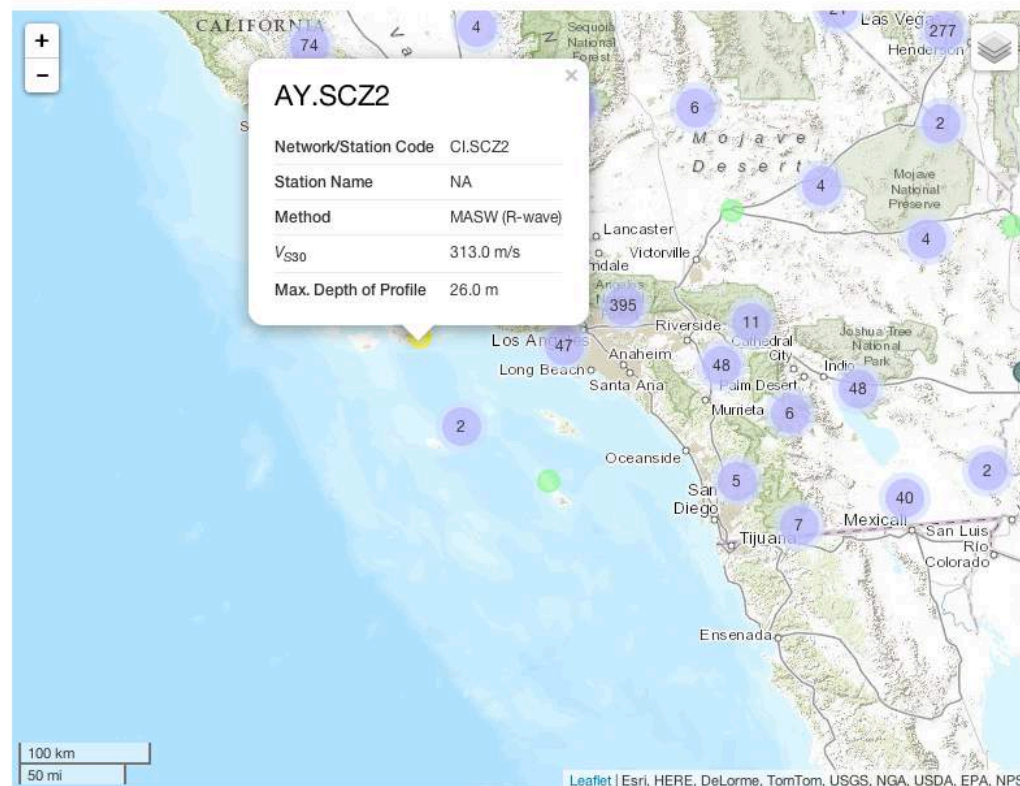
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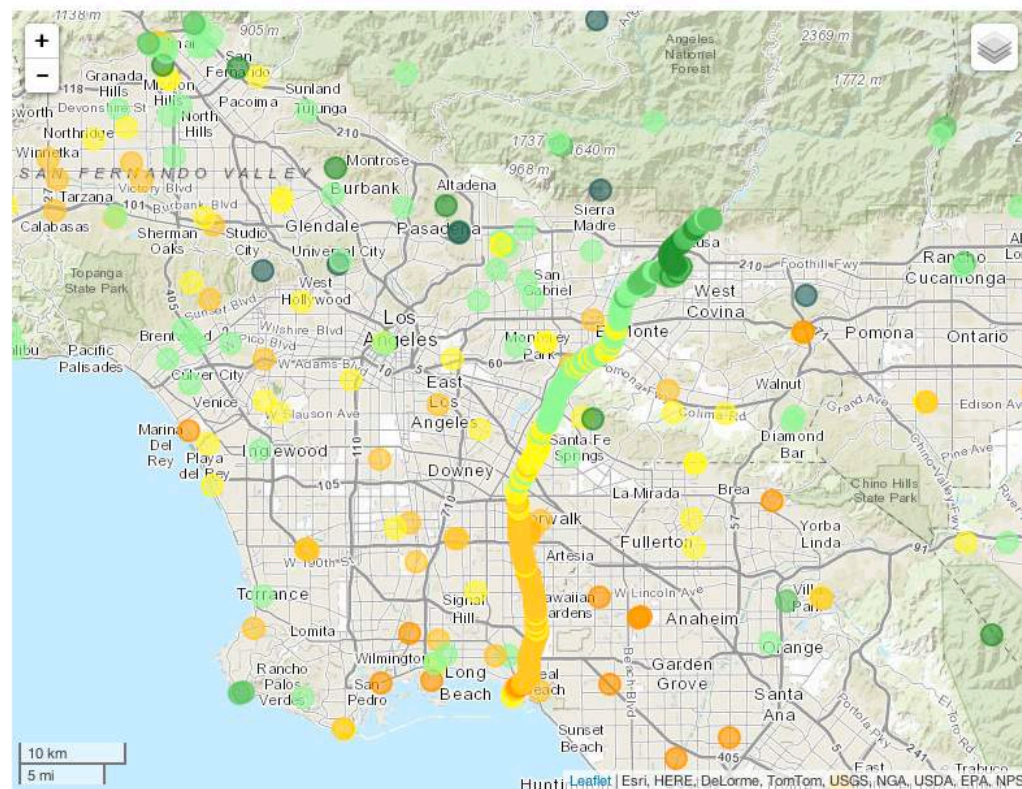
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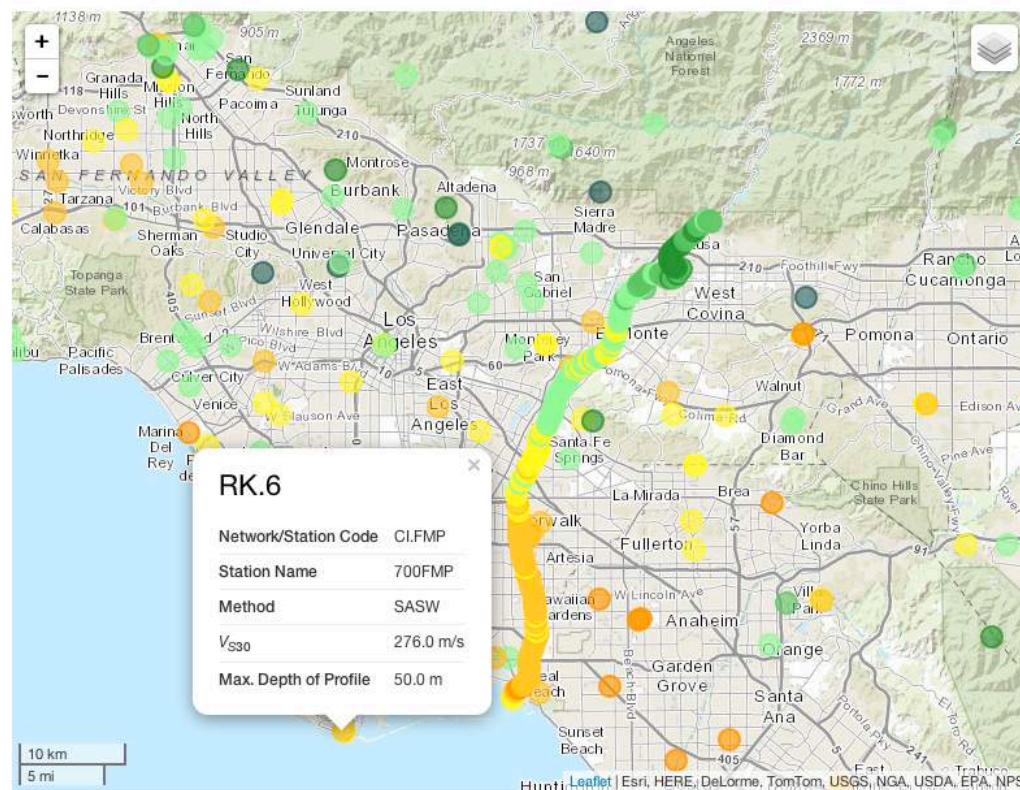
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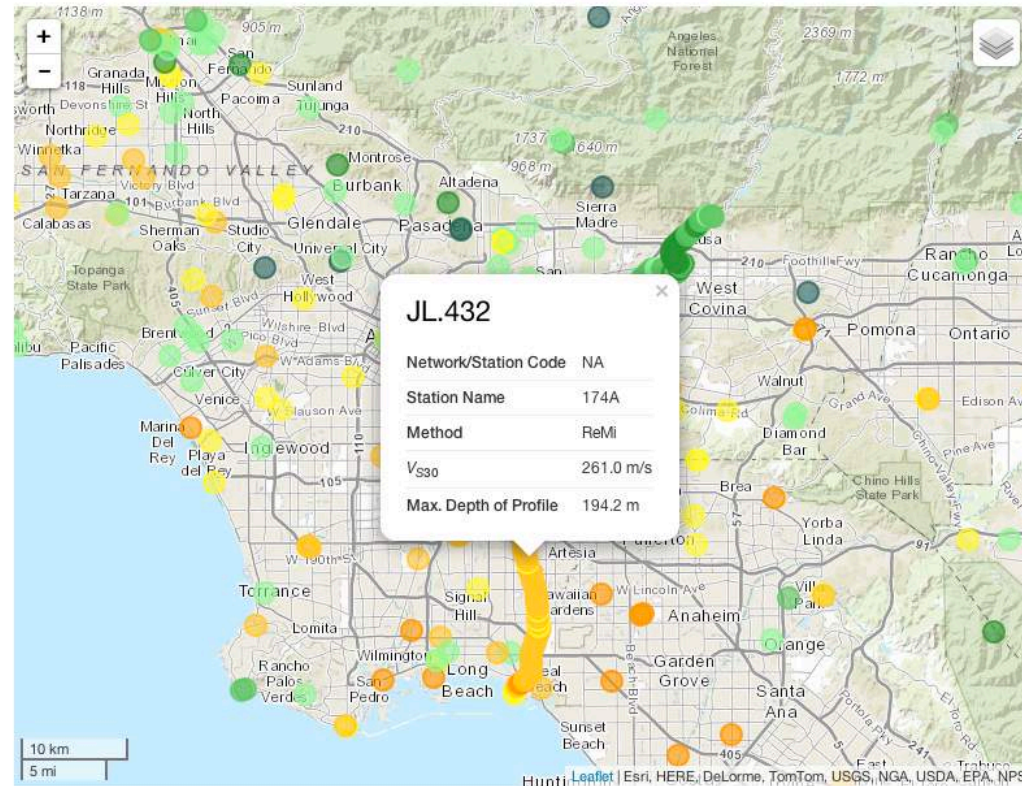
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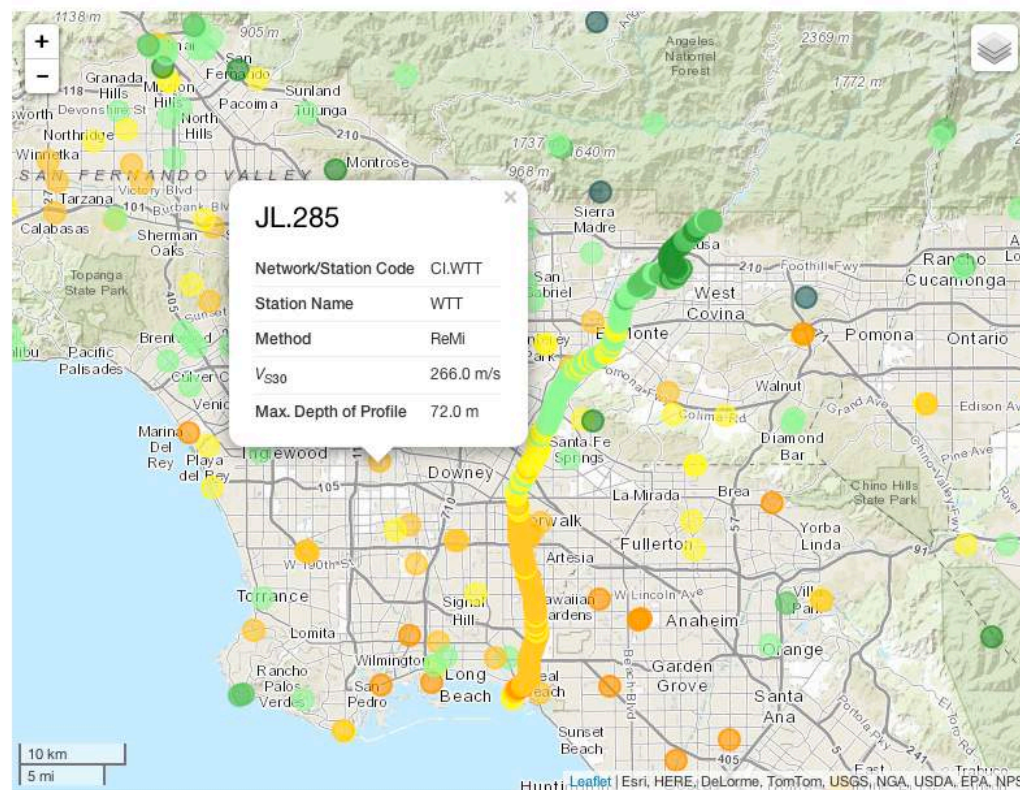
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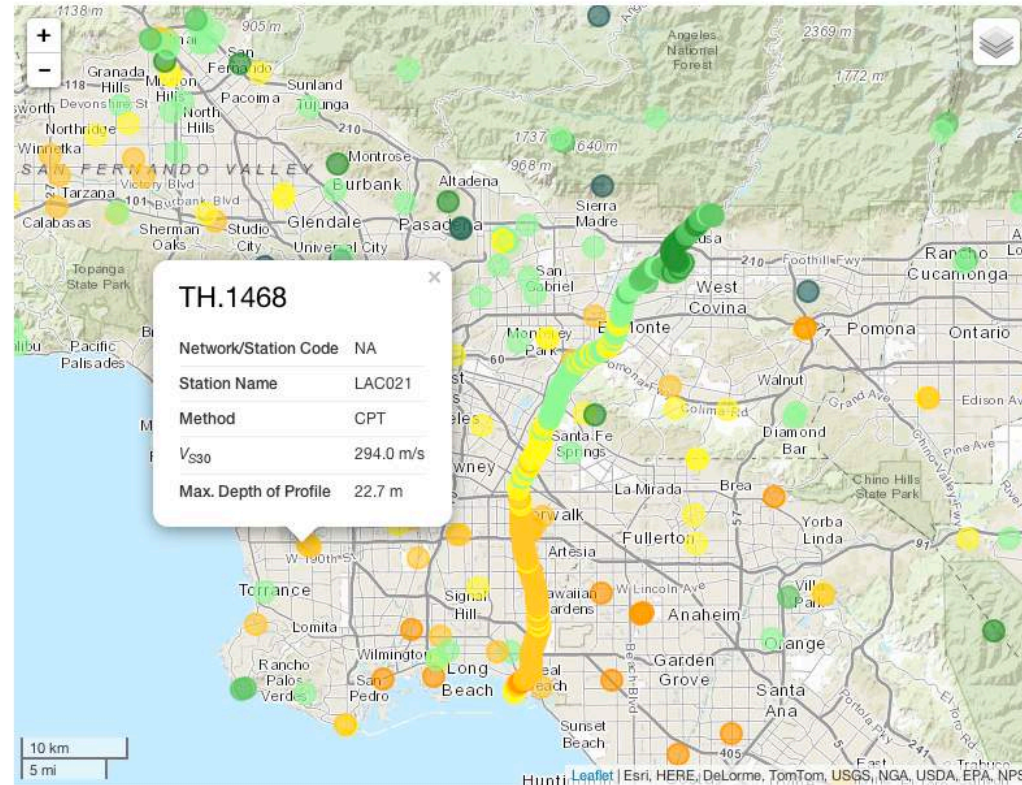
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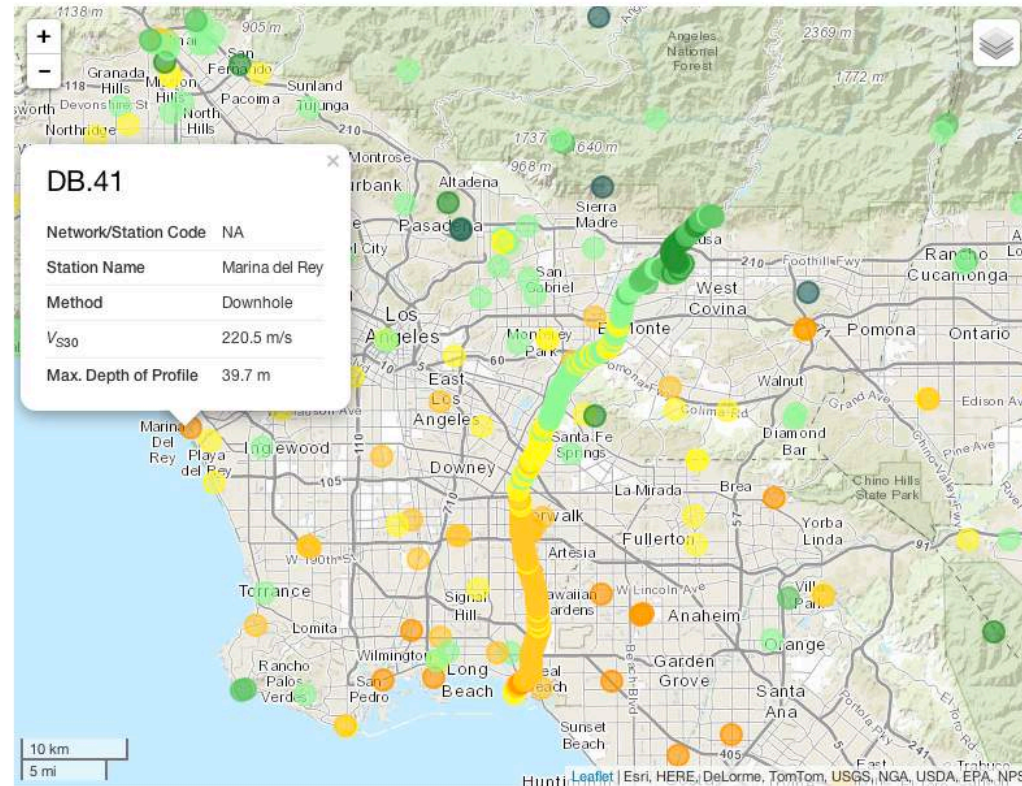
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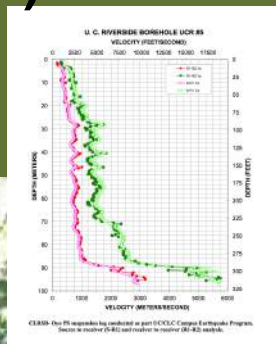
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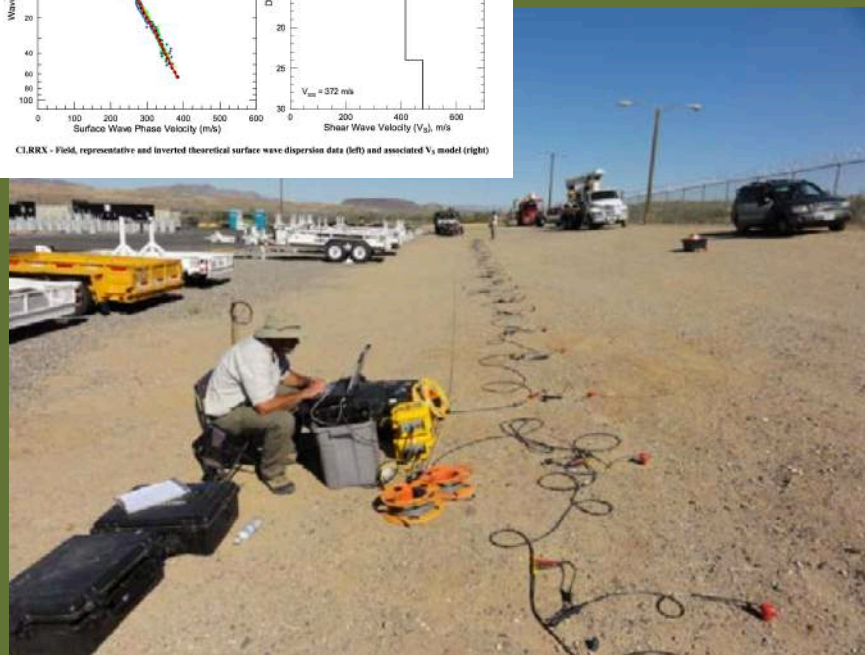
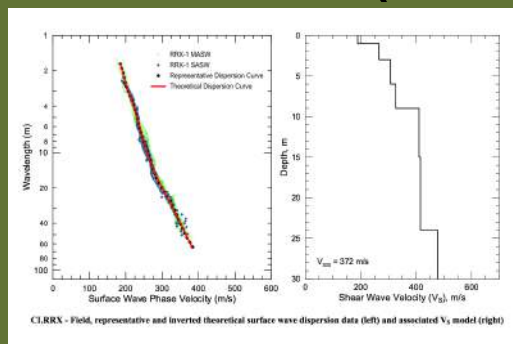
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Geophysical Techniques

Invasive
(PS-suspension)

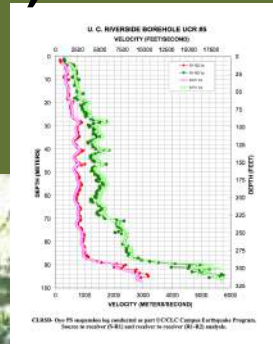


Non-invasive
(MASW)

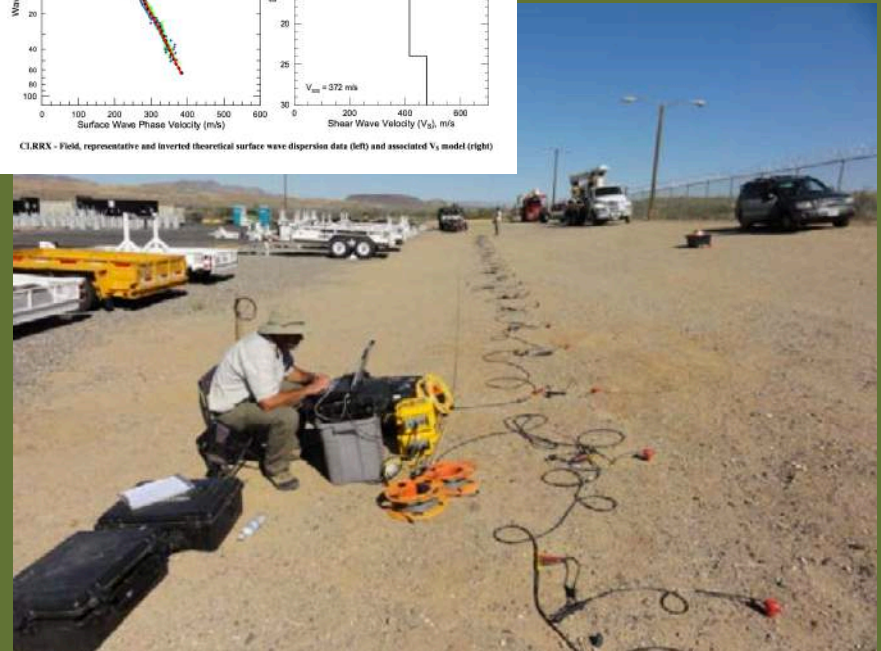
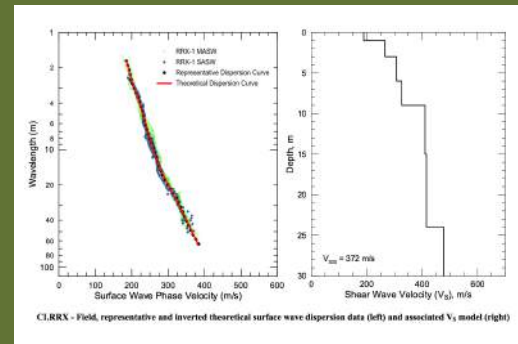


Geophysical Techniques

Inva**\$\$\$\$**ive
(PS-suspension)



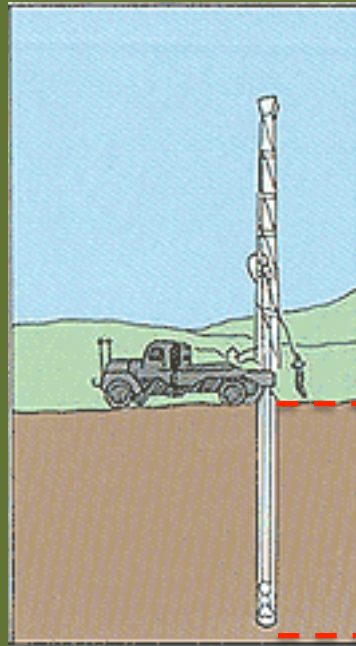
Non-invasive
(MASW)



Inva\$ive/Borehole Technique\$

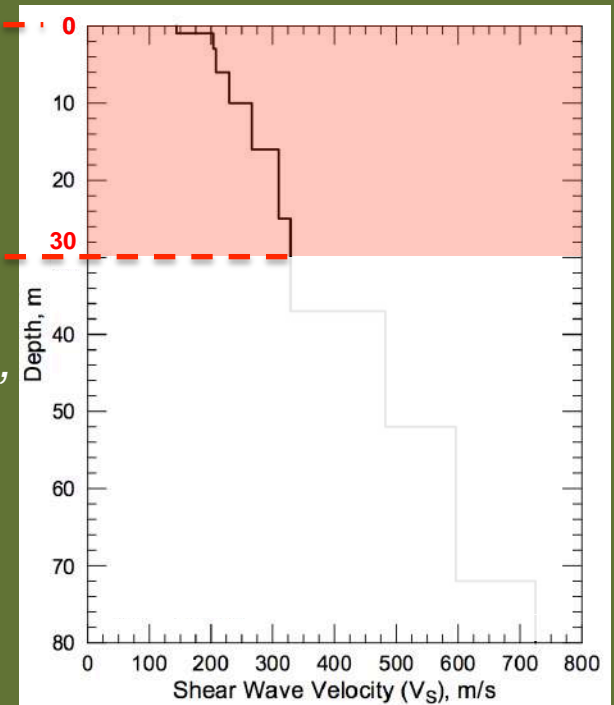


Photo Credit: Cécile Cornou



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

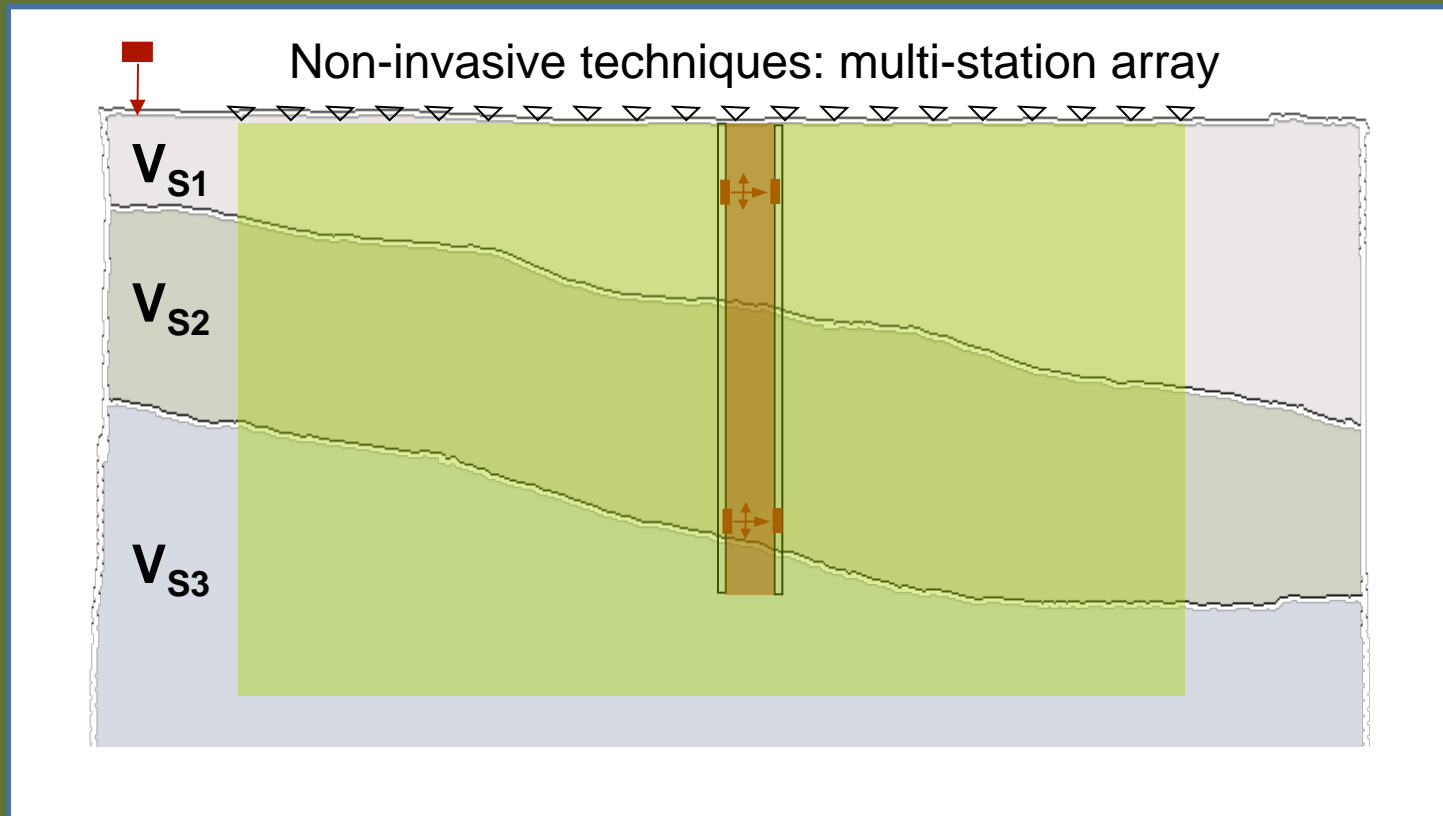
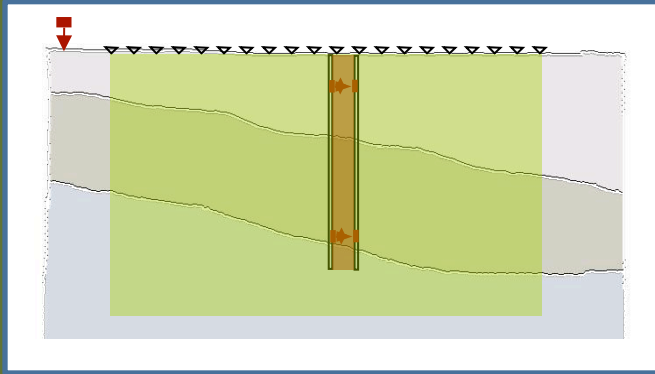


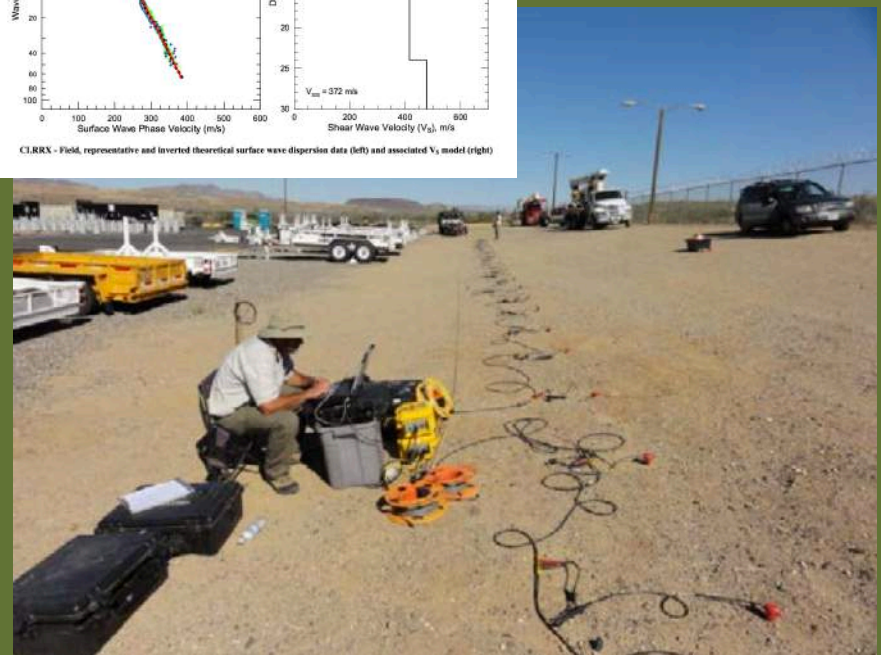
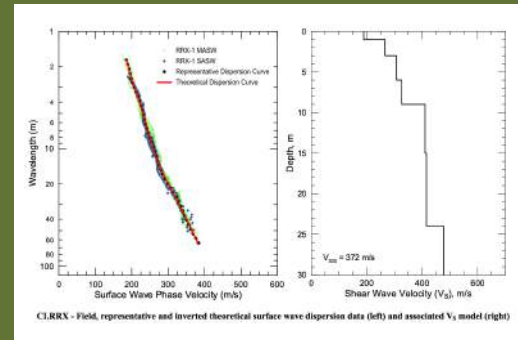
Figure Credit: Cécile Cornou

Geophysical Techniques

Non-invasive (MASW example)



- 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

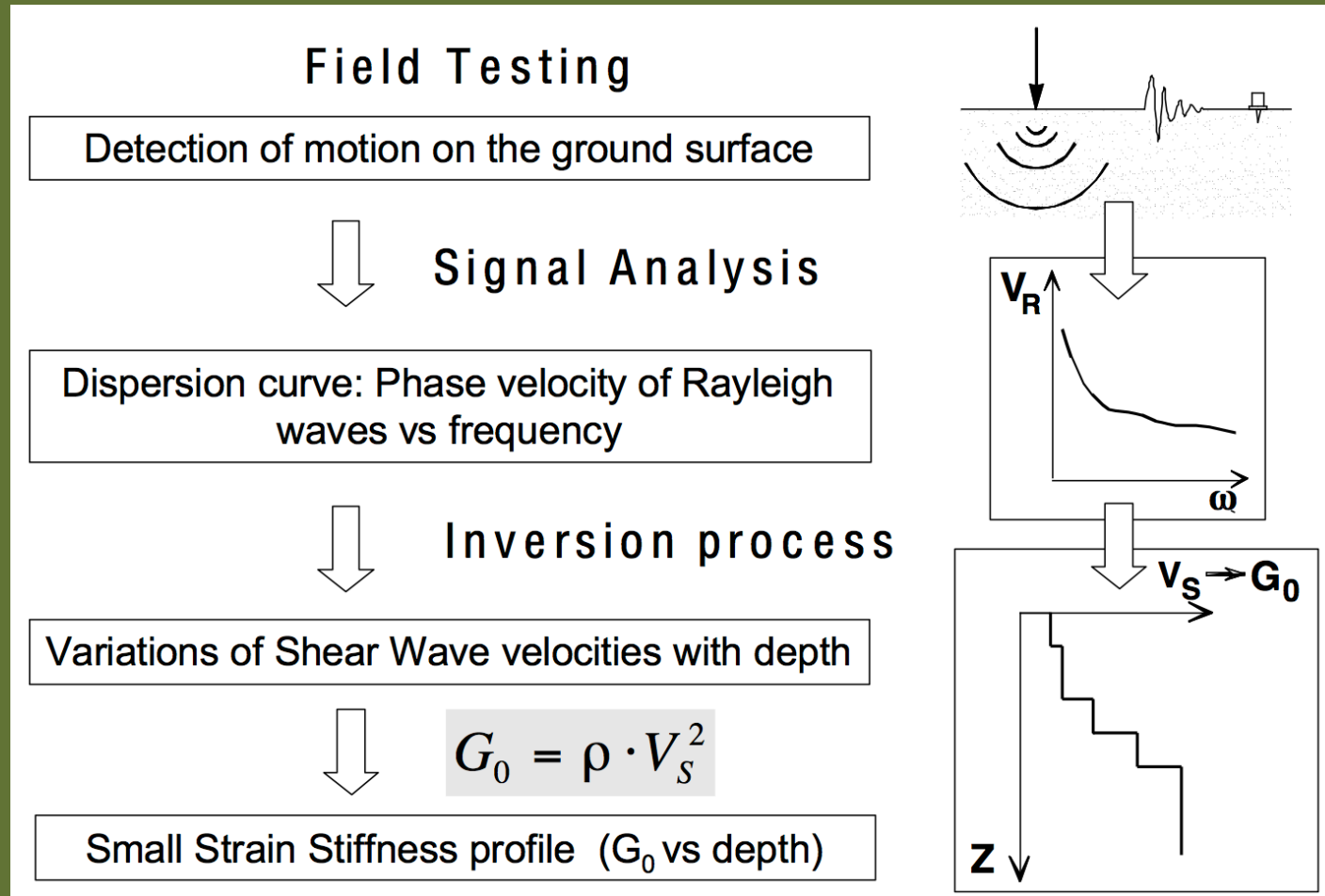
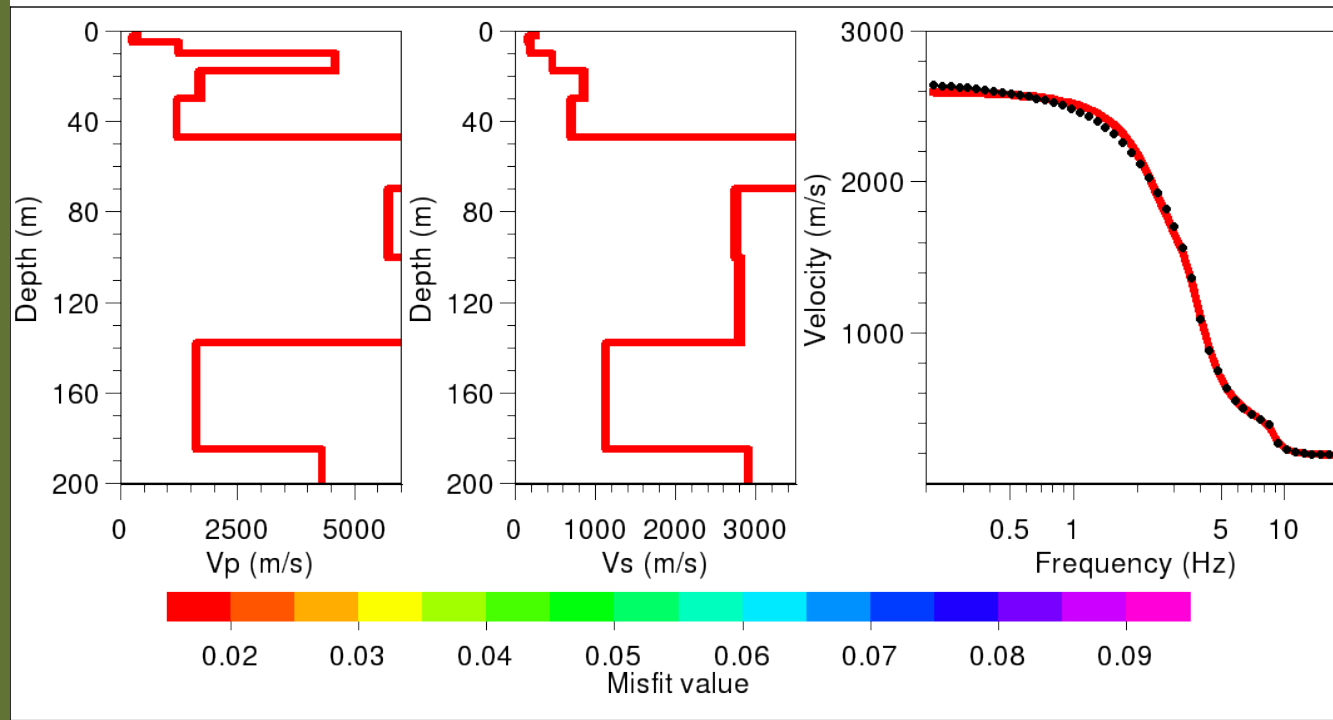


Figure Credit: Sebastiano Foti

Non-invasive Techniques

Rayleigh Wave Processing; Inversion; Pitfalls

Dangers of unconstrained least square approach surface wave inversion



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

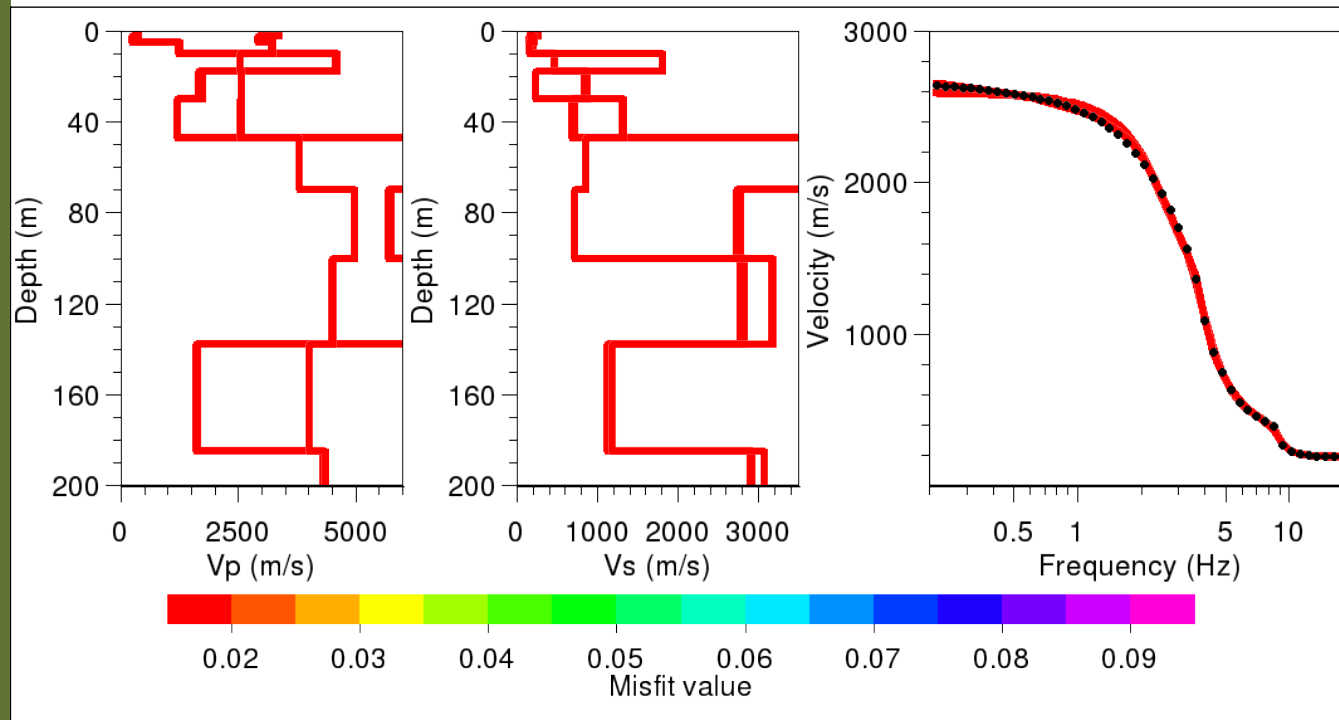


Figure Credit: Cécile Cornou

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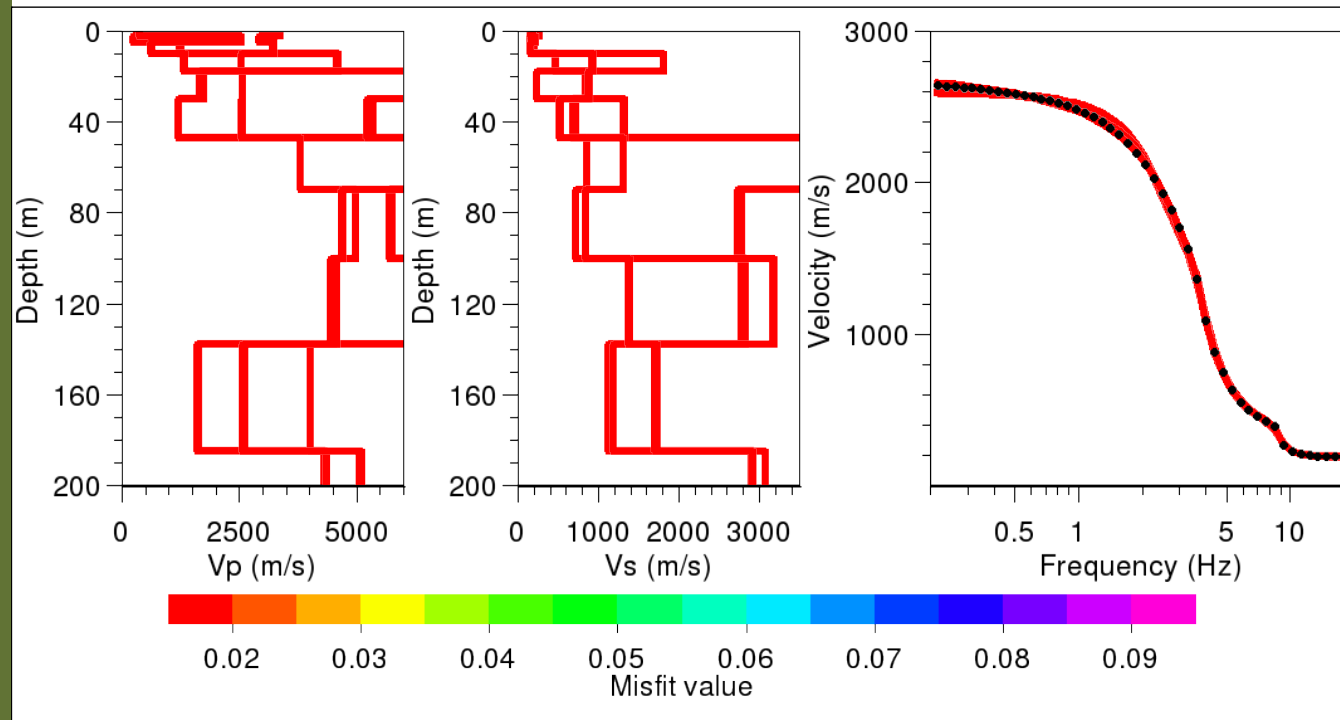


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Using ambient vibration techniques for site characterization
February 6th-12th, 2012, Las Vegas, USA



Figure Credit: Cécile Cornou

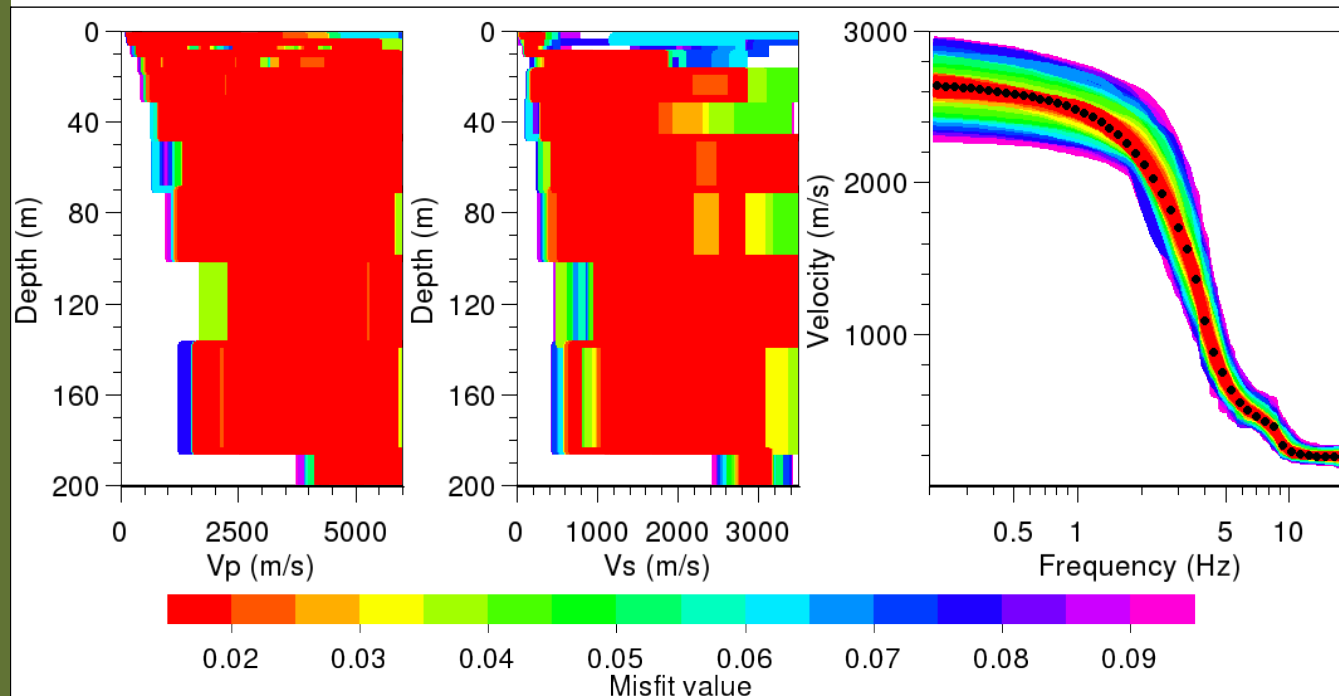
SCEC 3D Site Effects Workshop
5 May 2015 at SCEC Media Center, USC



Non-invasive Techniques

Rayleigh Wave Processing; Inversion; Pitfalls

Dangers of unconstrained least square approach surface wave inversion



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



Figure Credit: Cécile Cornou

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 analysts, synthetics (no real borehole measurements)
- Cox *et al.* (2014): one site, several methods, several analysts, no borehole measurements

- **SUMMARY:**

- **Low variability in dispersion estimates**
- **Large variability in inverted shear-wave velocity profiles**
- **Low variability in V_{s30} estimates**



2009

American Recovery & Reinvestment Act

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



Open-File Report 2013-1102

>> Pubs Warehouse > OF 2013-1102

ARRA-Funded V₅₃₀ 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 V₅₃₀ (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 V₅₃₀ 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 V₅₃₀ 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/>

Part of this report is presented in Portable Document Format (PDF); the latest version of Adobe Reader or similar software is required to view it. [Download the latest version of Adobe Reader, free of charge.](#)

Suggested citation:

Yong, A., Martin, A., Stokoe, K., and Diehl, J., 2013, ARRA-funded V₅₃₀ 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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Data repository

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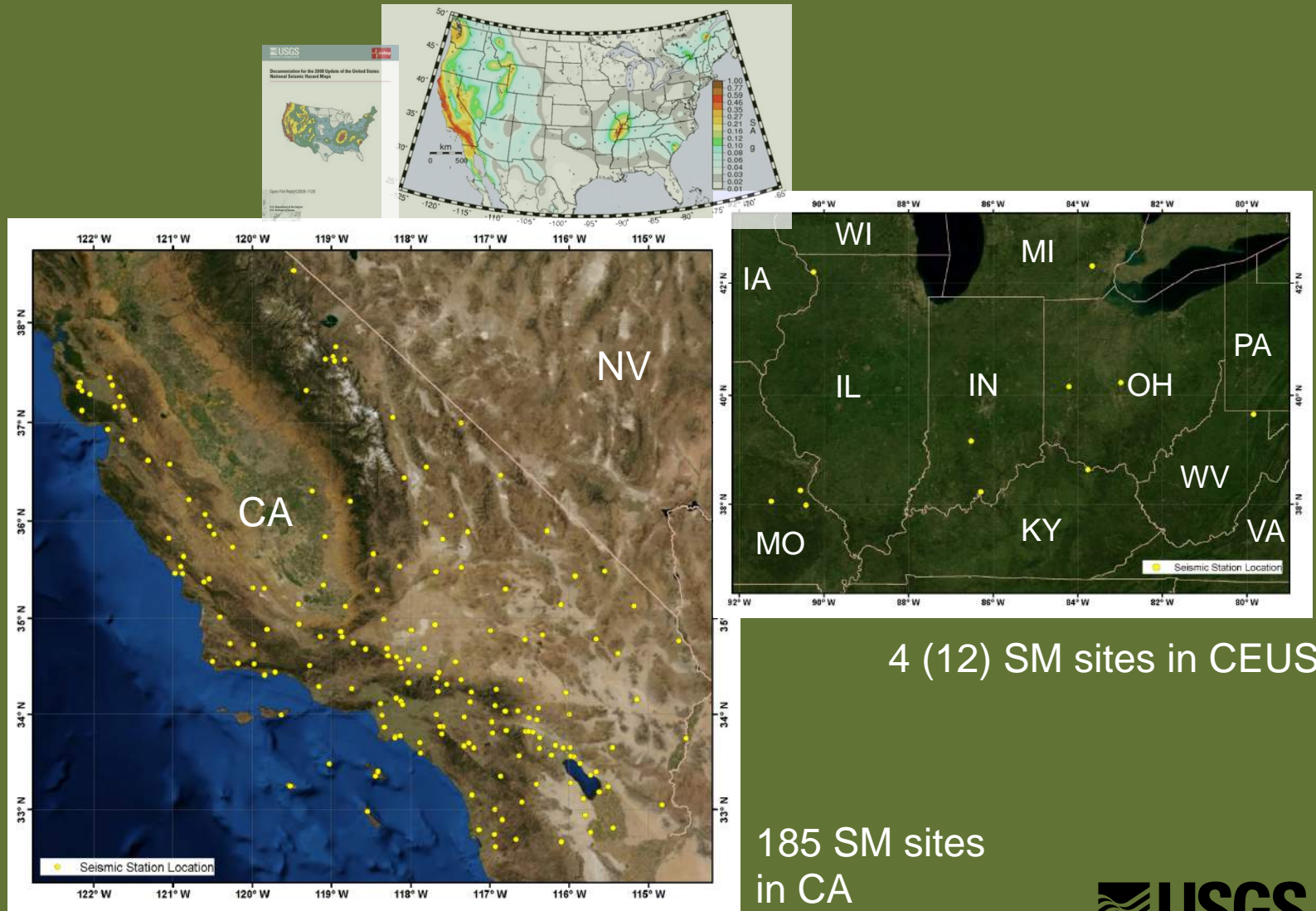
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ARRA: Strong Motion Station Site Selection



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

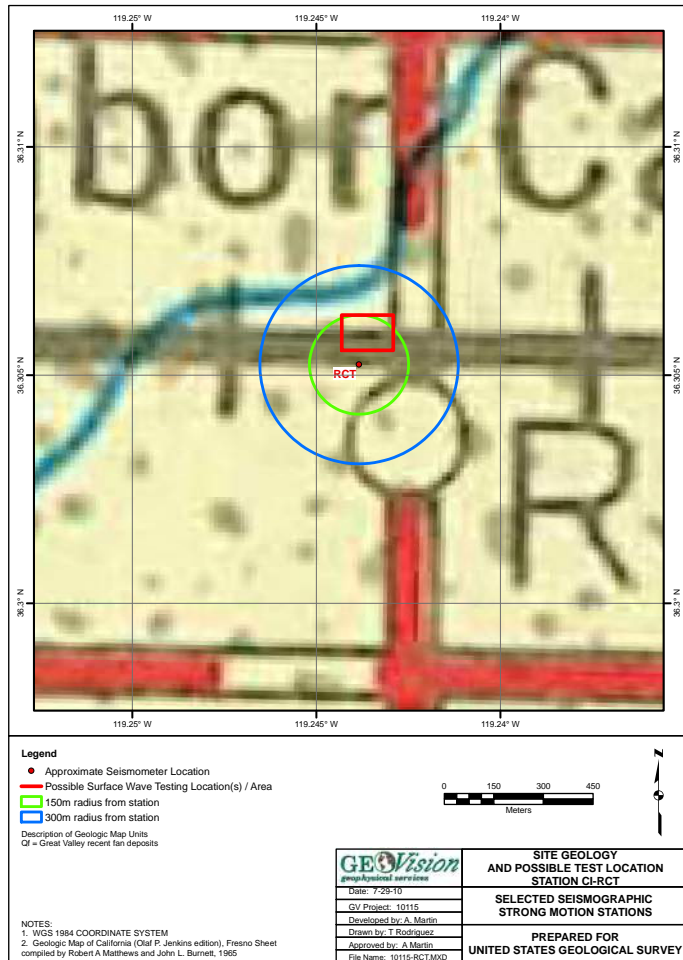
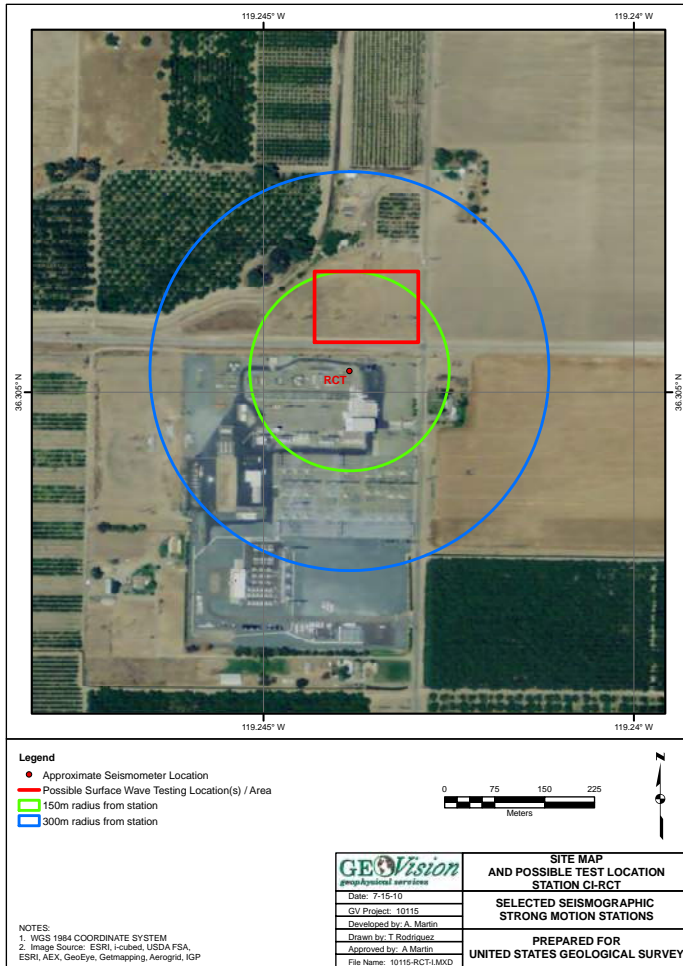
ARRA: Geophysical Techniques Based on Site Conditions

Types of Site Conditions	Geophysical Techniques					
	H/V Spectral Ratio	P-Wave Seismic Refraction	Active Surface Wave		Passive Surface Wave	
			SASW	MASW	Array Microtremor	ReMi TM
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)





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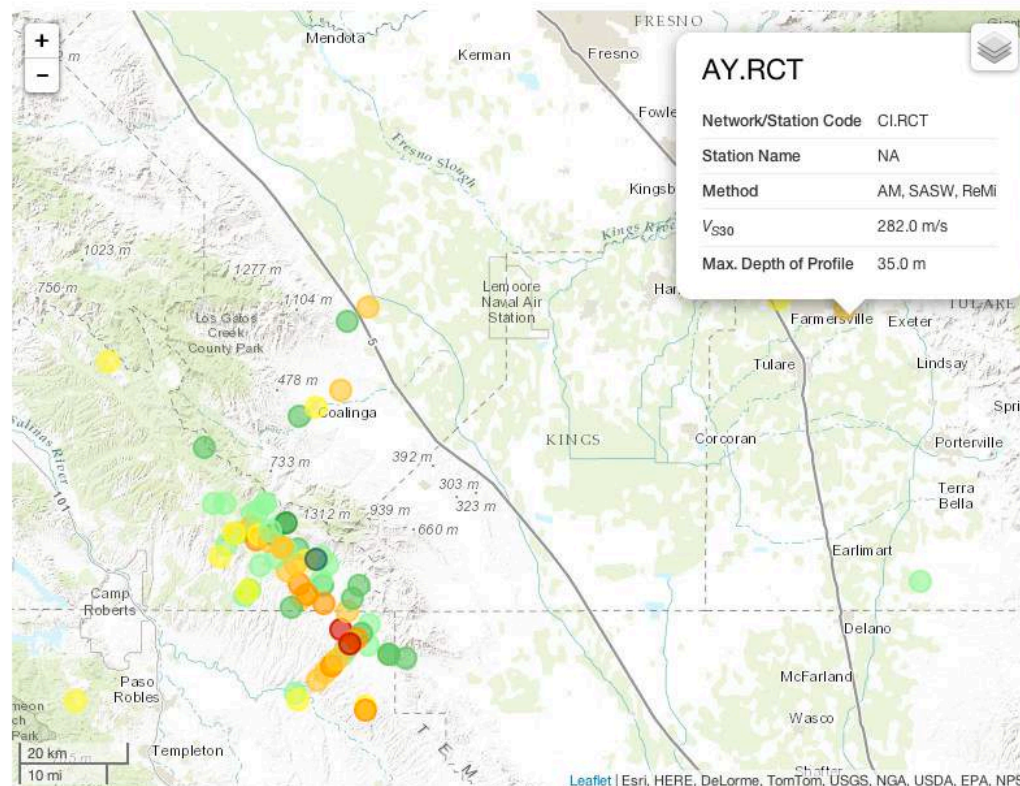
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A Compilation of VS30 Values in the United States

VS30, 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 VS30 funded by the USGS and other governmental agencies for 2997 sites in the United States.



VS30 Ranges (m/s)

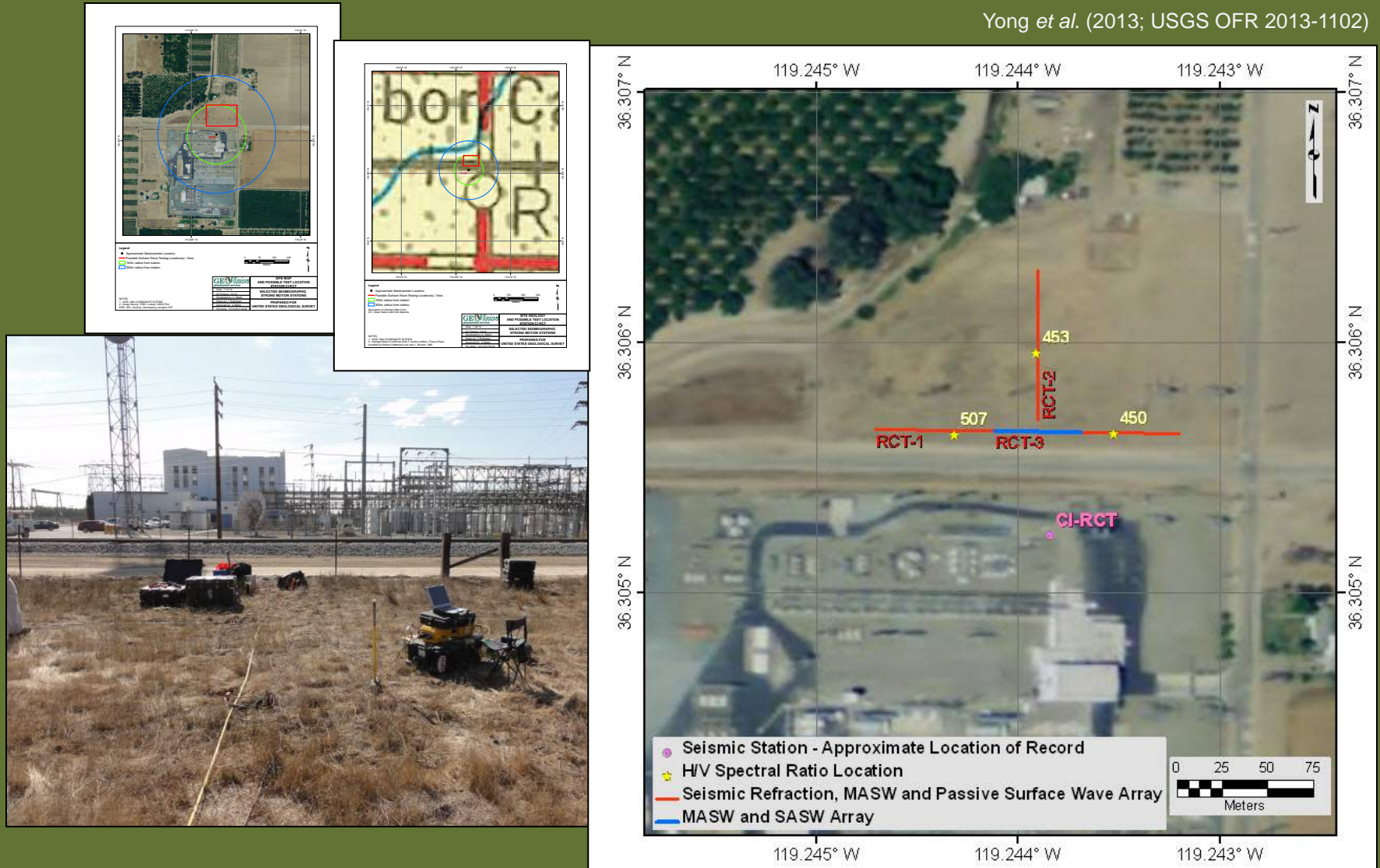
No value
 < 180
 180–240
 240–300
 300–360
 360–490
 490–620
 620–760
 > 760

[Download VS30 Data \(.csv format\)](#)

ARRA: Non-invasive Techniques

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

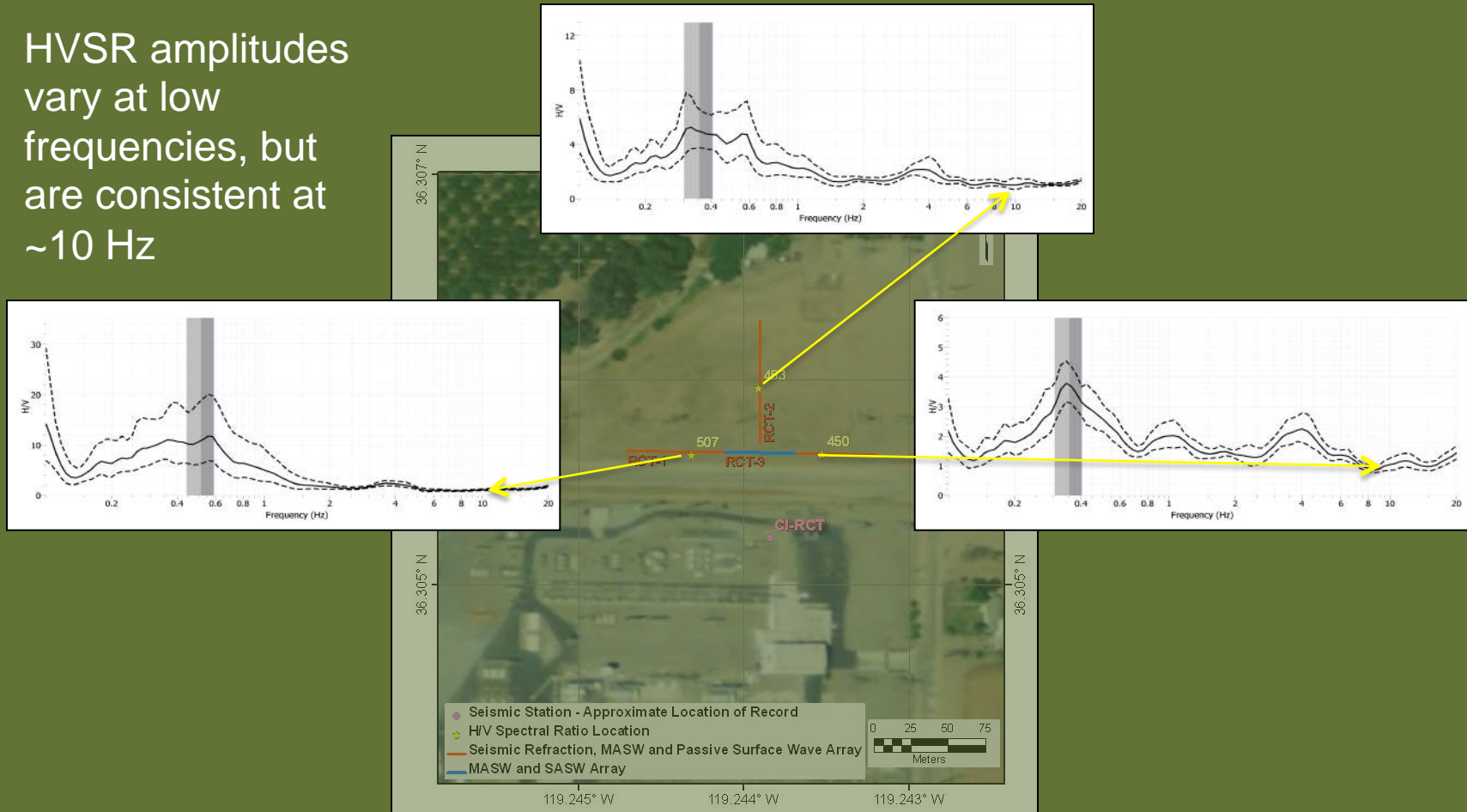
Yong *et al.* (2013; USGS OFR 2013-1102)



ARRA: Non-invasive Techniques

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

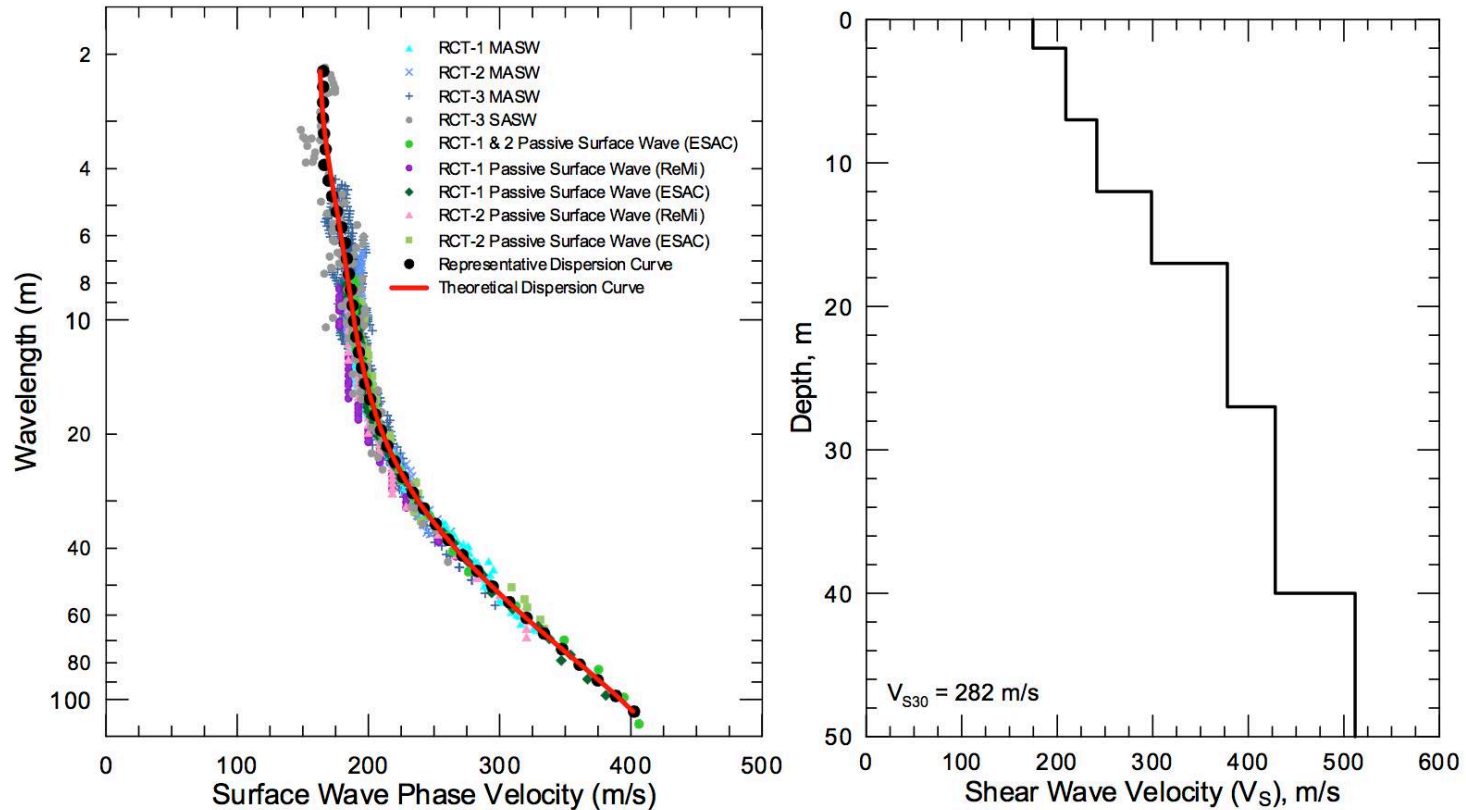
HVSR amplitudes vary at low frequencies, but are consistent at ~10 Hz



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

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)

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



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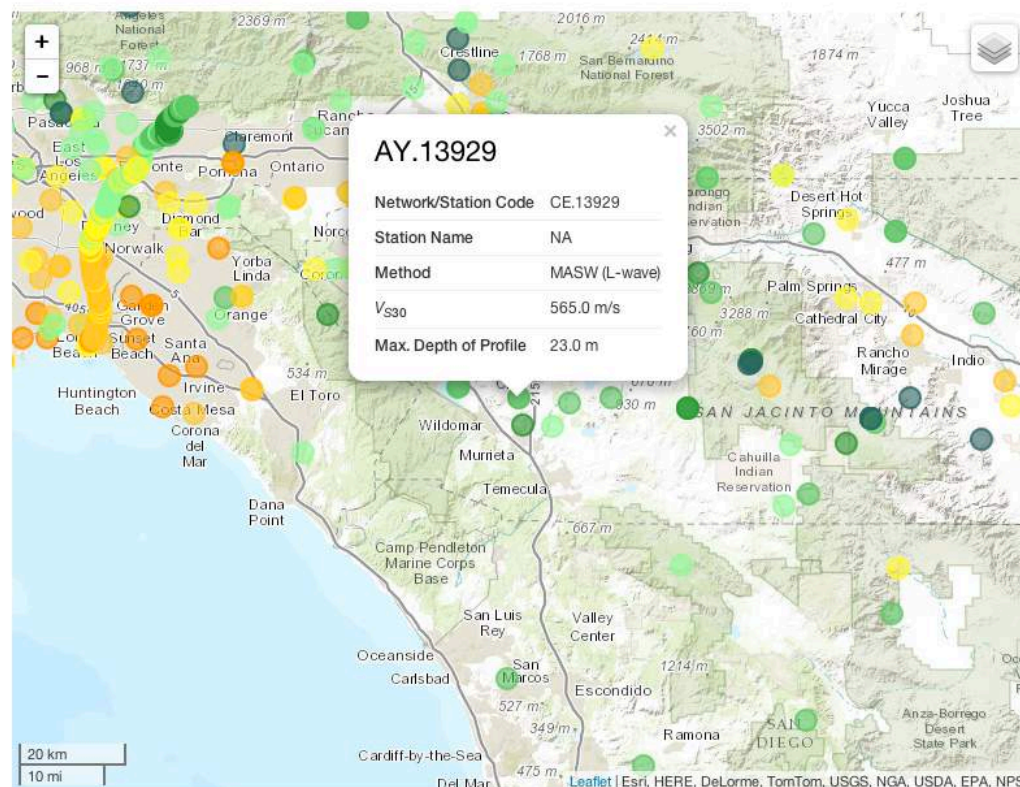
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A Compilation of V_{S30} Values in the United States

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

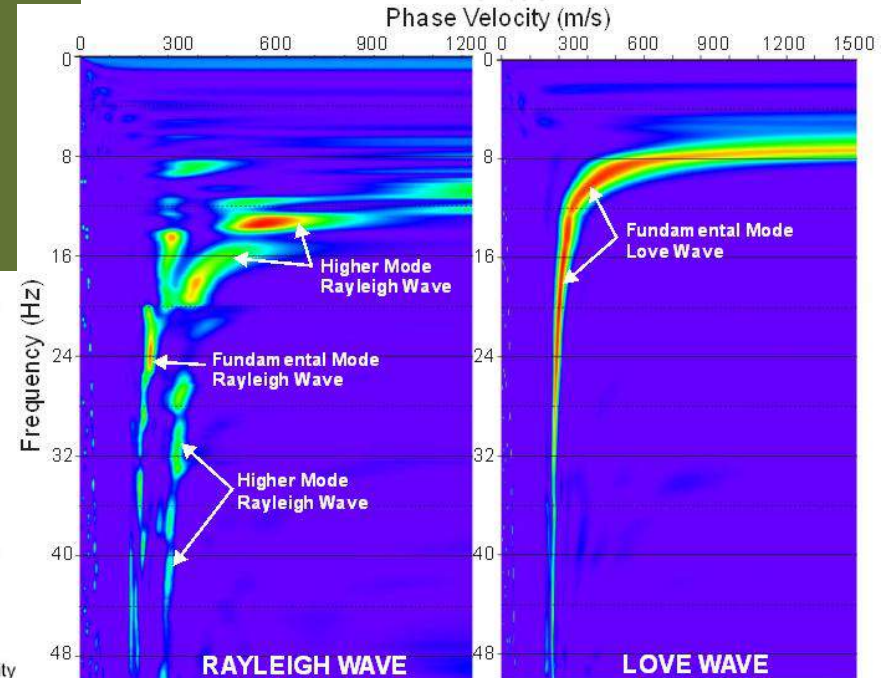
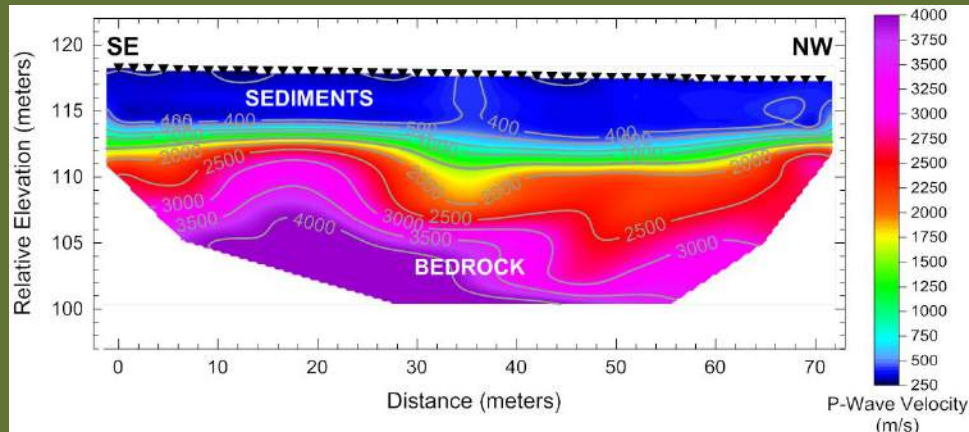
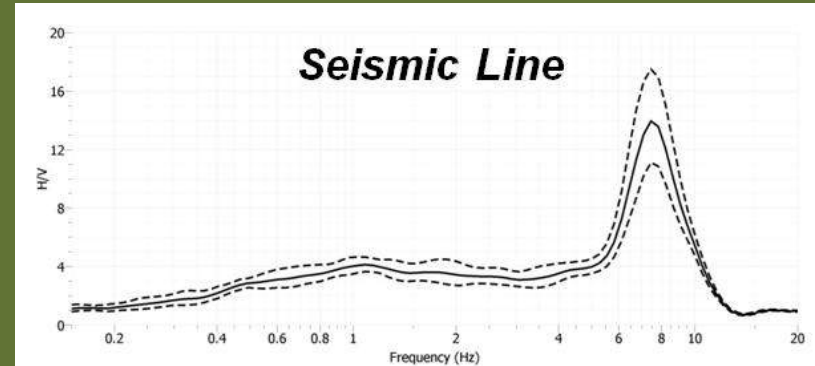
[Download \$V_{S30}\$ Data \(.csv format\)](#)

ARRA: Non-invasive Techniques

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

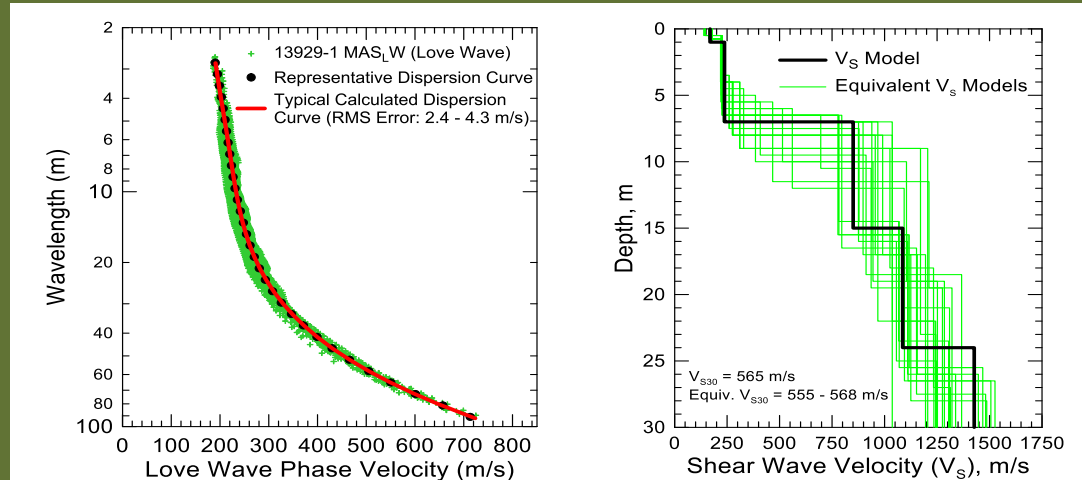
- Shallow rock site according to P-wave seismic refraction model and high frequency HVSR peak (7.5 Hz).
- First site in the ARRA project where $MAS_R W$ ineffective but $MAS_L W$ effective.
 - Complex Rayleigh wave propagation.
 - Fundamental mode Love wave is very clear.

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.

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 expensive/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 expense (“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.

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