Advances in Seismic Methods

FOR NUCLEAR PLANT SITE CHARACTERIZATION

John Diehl, MS, PE
President, GEOVision Geophysical Services
https://geovision.com

About Me

- BSME Cal Poly Pomona
- MSCE & MBA UCLA
- Authored/coauthored 30 publications
- Lifetime member of ASCE
- PE in the state of California
- Cofounded GEOVision in 1995

About GEOVision

- Since 1995
- All 5 founders still involved
- Couldn’t find anyone in SoCal to do high quality geophysics
- Full suite of geophysical services for customers worldwide
- Over 120 NPP projects worldwide

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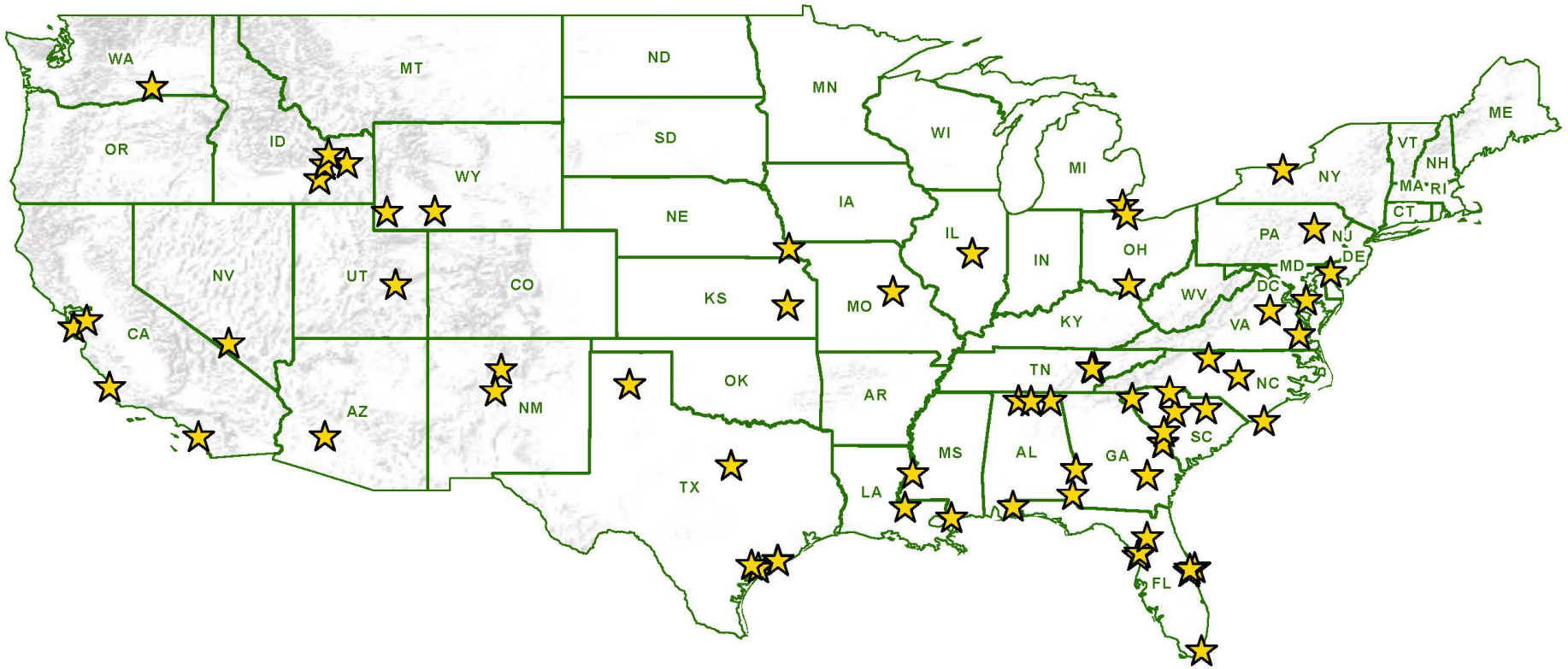
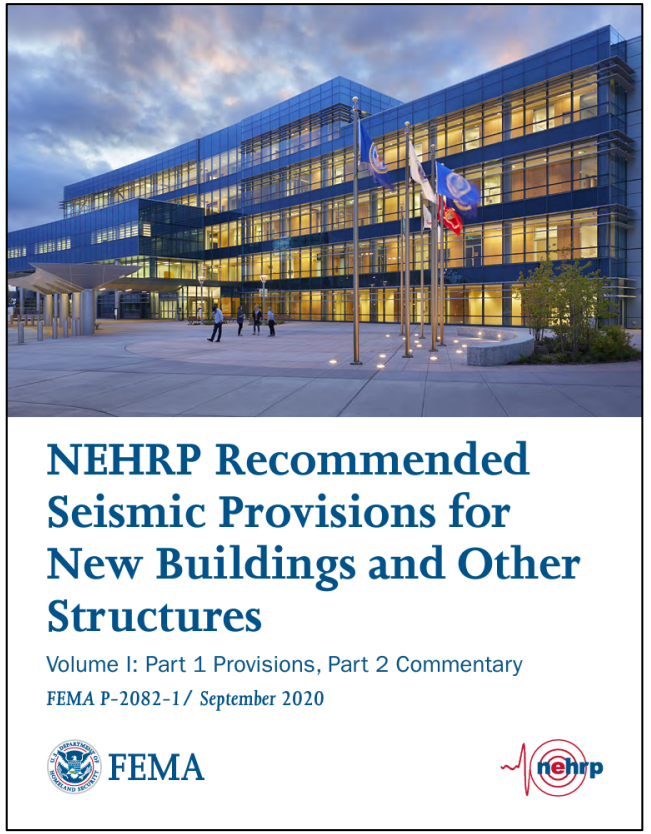
NPP Projects in the USA



How Seismic Methods help Geotechs

- Site Classification (Vs30, shear wave profile)
- Determine depth to bedrock, water table
- Rippability of rock
- Soil and rock properties
- Fault location and orientation
- Data for site response analysis



Currently available seismic methods

- **Surface Methods**
  - Seismic Refraction (ASTM D5777)
  - Seismic Reflection (ASTM D7128)
  - Surface wave methods including
    - SASW
    - MASW, MALW
    - H/V spectral ratio
    - array microtremor
    - refraction microtremor

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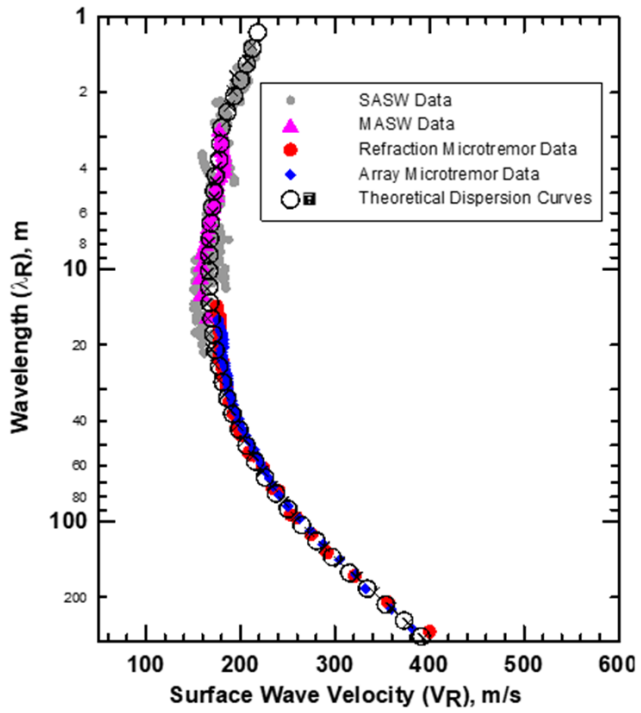
newest

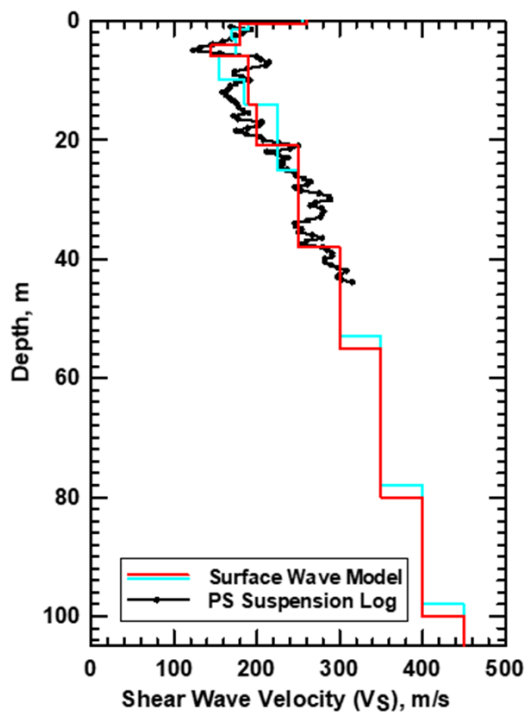
Surface Wave Surveys

A Multimethod approach is necessary! Why?

- We rarely know in advance what tools will be needed, so we need the whole toolbox
- Sites can be complex (higher modes), and simple Rayleigh wave MASW may not work
- Includes different sources, and methods
- Sources can be impulsive, low or high energy, or vibratory
- Methods are complimentary
  - Borehole or surface
  - SASW, MASW and/or MALW (Love wave)
  - Active and passive
  - Linear or 2D (not ReMi, usually)



Field Data and Theoretical Dispersion Curve



VS Model

Seismic Sources

Hammer Energy Sources

Accelerated Weight Drop

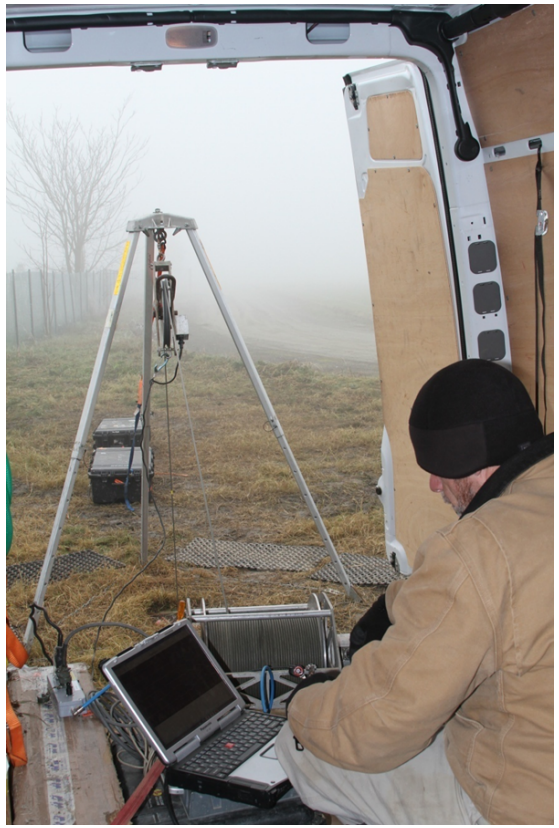
EnviroVib

Electromechanical Shaker

Bulldozer Energy Source

Currently available seismic methods

- **Borehole Methods**
  - Downhole seismic (ASTM D7400)
  - Crosshole seismic (ASTM D4428)
  - P- and S-wave Suspension Logging (sometimes referred to as OYO Suspension logging)



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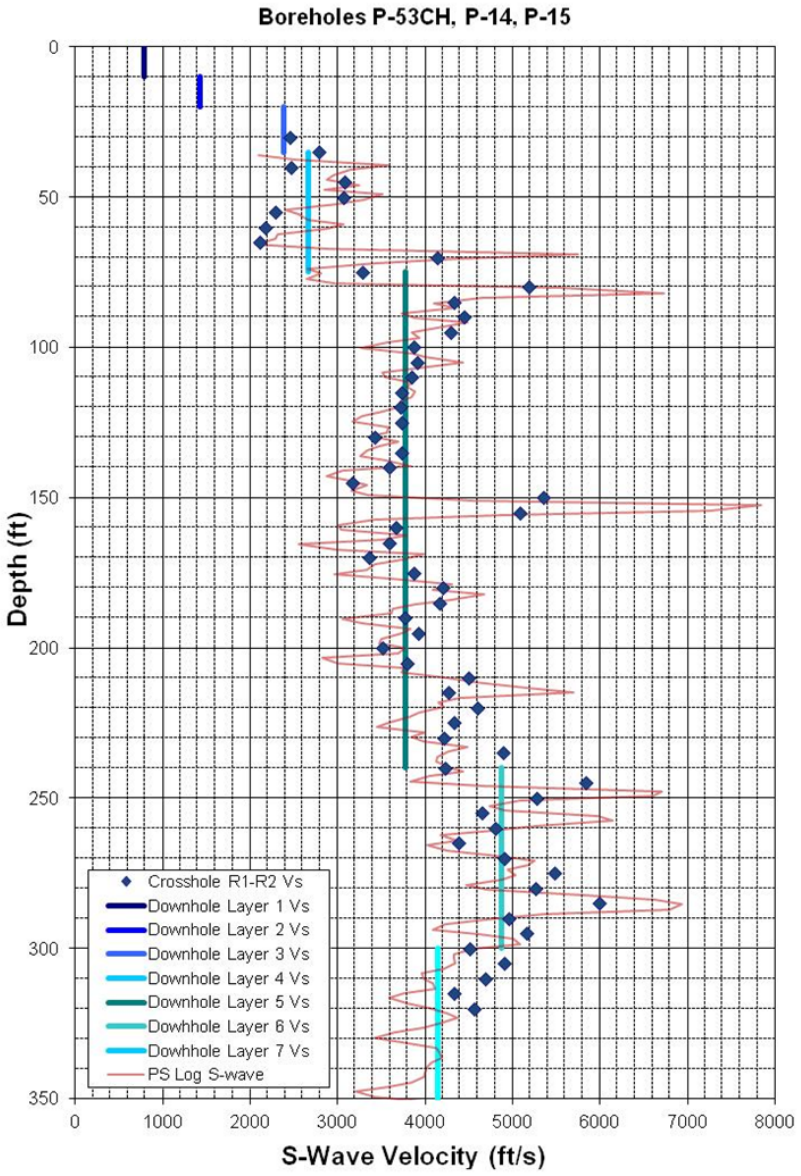
Borehole techniques for shear wave

- Suspension Logging – single tool containing source and receivers
- Down-hole – receivers lowered down borehole with source at surface
- Cross-hole – source in one borehole, receivers in another



What is the future for seismic methods?

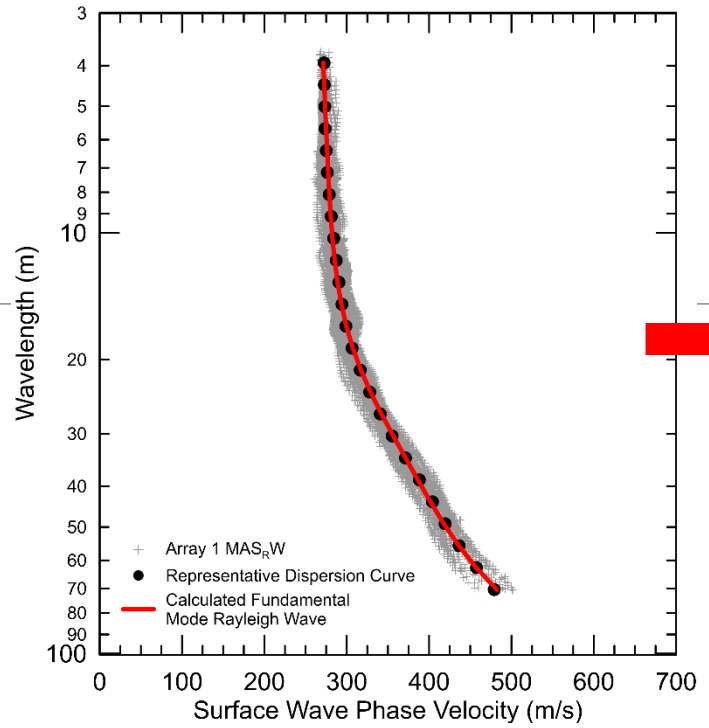
- Bringing state-of-the-art to state-of-practice (new ASTM standards); particularly for Surface Wave methods and P-S Suspension logging.

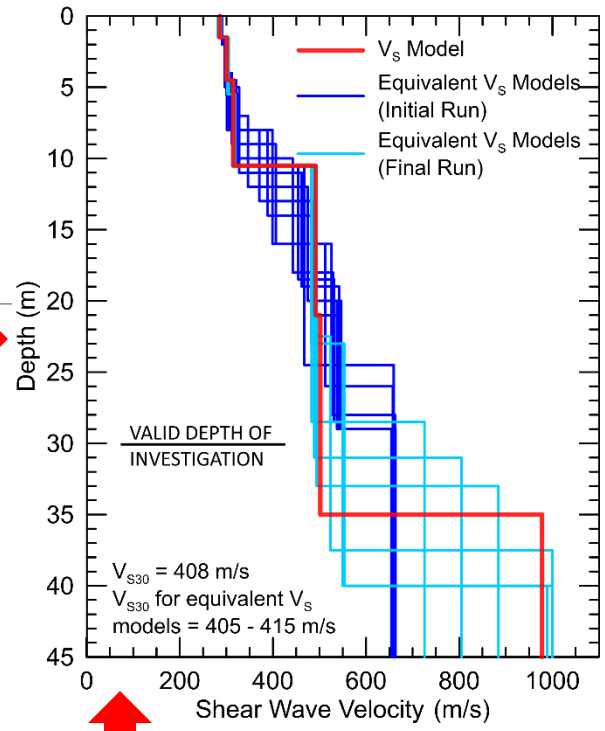
What is the future for surface methods?

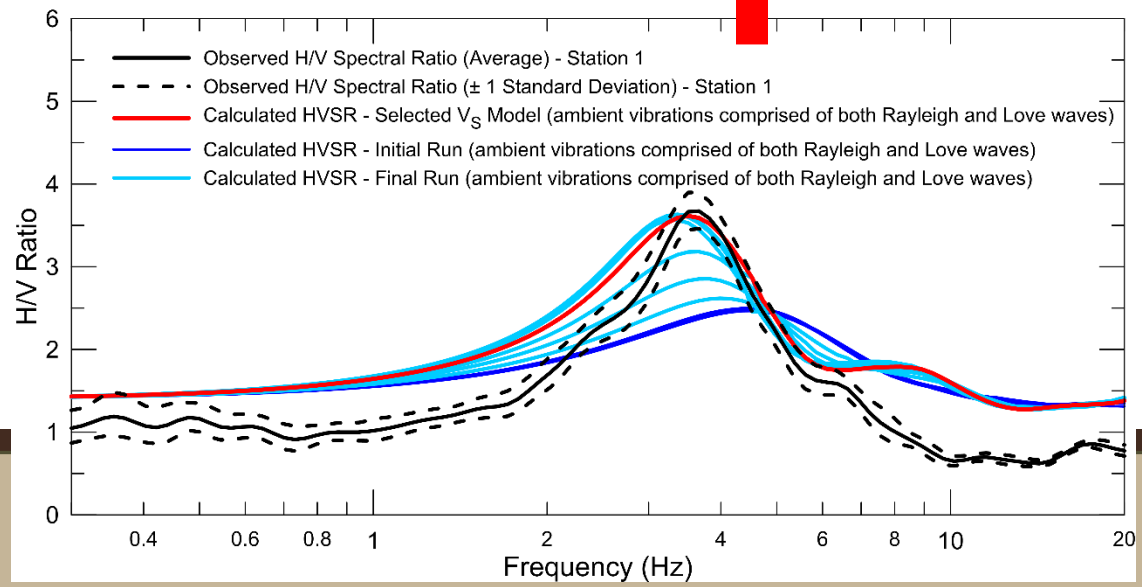
- Incorporate H/V spectral ratio into site response studies
- Explore using 3 component sensors for better joint Love - Rayleigh wave analysis
- Explore how AI can help
  - Better inversion
  - Better modeling
- Standardize methods for measuring damping

Reconciling V_S Models with HVSR

- Site CE.58135 – UCSC Lick Electric Shop, Santa Cruz, California.
- Surface wave depth of investigation is about 30 - 35 m based on λ_{max} = 70 m.
- Initial ensemble of V_S models are not compatible with observed HVSR. HVSR response almost identical for the models (shown in dark blue).
- V_S model depth extended with higher velocity half space to better fit observed HVSR (shown in light blue). Half space velocity not well constrained.
- V_{S30} similar for all V_S models (405 – 415 m/s)







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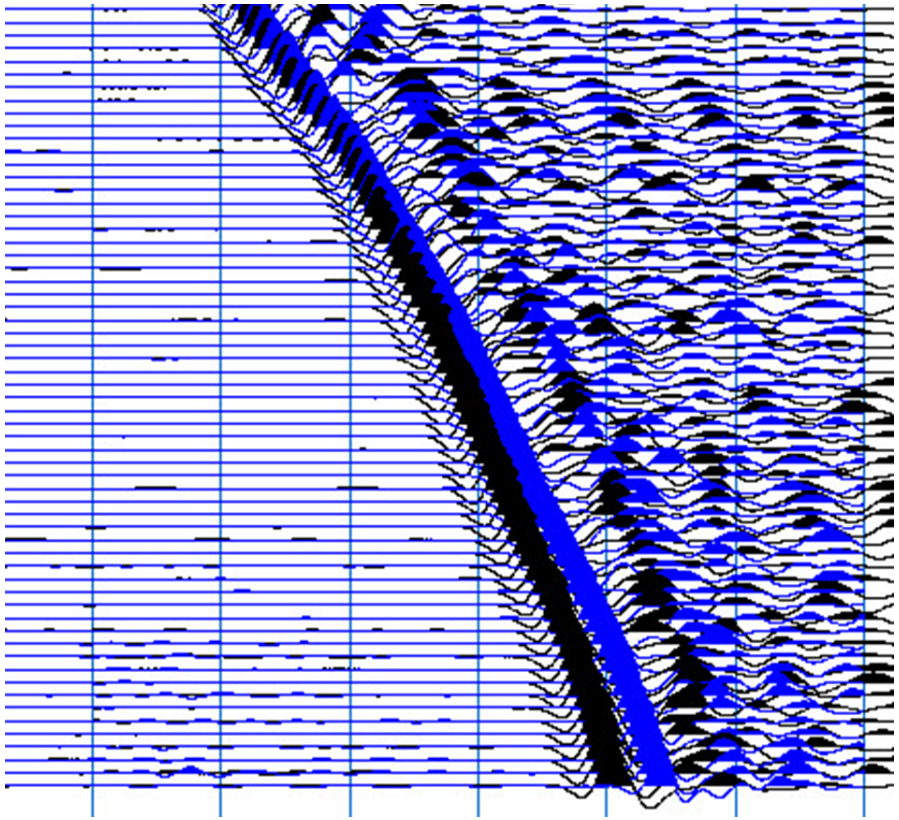
What is the future for borehole seismic methods?

- Confront the issue of anisotropy
  - It does exist, more often than you think, but we don’t check for it
  - How to check?
    - Multi-plank orientations during Downhole measurements
    - Develop new P-S Suspension tools that have built-in orientation logging

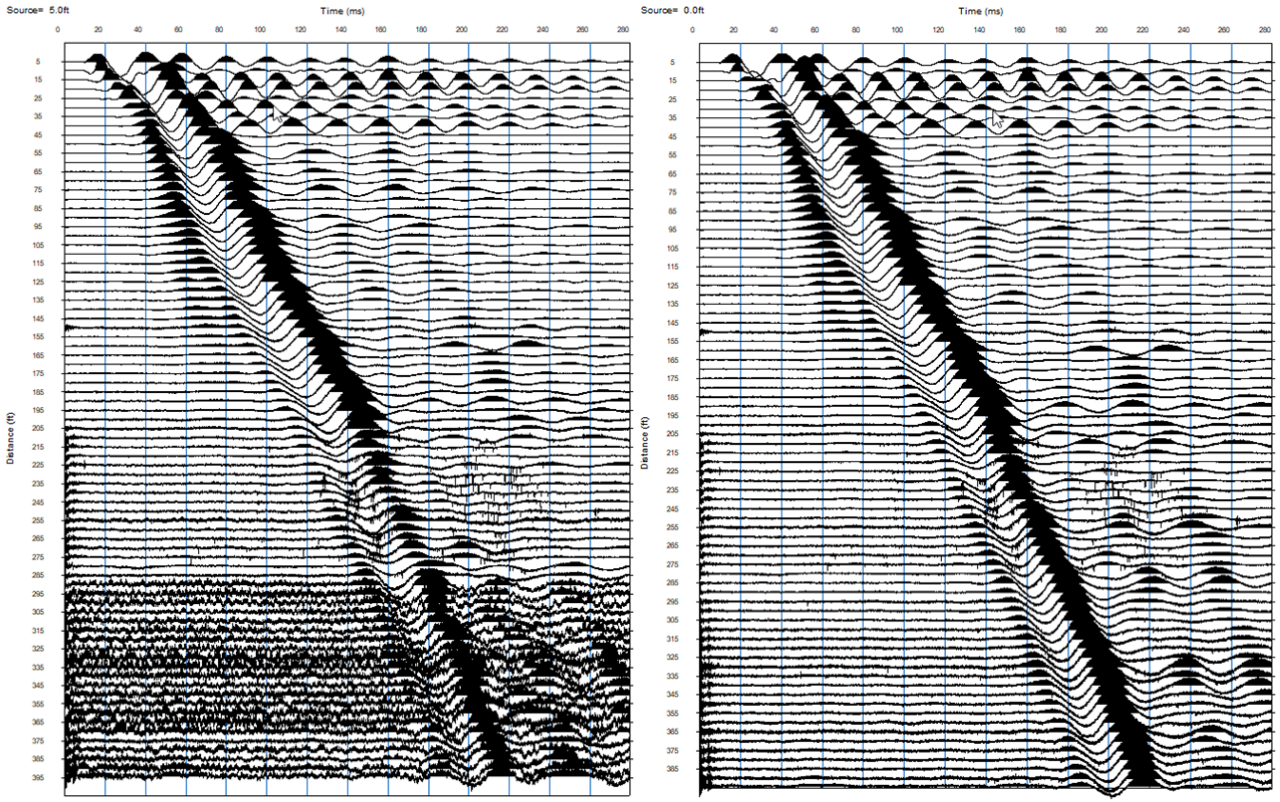
Example: Multiple plank operations to characterize S-wave splitting

- S-wave splitting observed from two plank orientations at same borehole.
- Polarization analysis required because axis of symmetry not parallel to plank orientations.
- 25 ms difference in first arrival at bottom of borehole (120 m depth).



What is the future for borehole seismic methods?

- Standardize on using polarization analysis to improve signal quality rather than depend on orientable geophones in Downhole seismic
- Standardize methods for measuring damping



What is the future for borehole seismic methods?

- Using Crosshole to measure both S_V and S_H in order to estimate overconsolidation ratio (OCR). Downhole and Suspension only measure $S_{H.}$ Currently, the Crosshole method, as commonly executed, only measures S_V
- Using borehole gravimetry to perform in-situ density measurements (vertical microgravity)

Questions?

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