Active and Passive Surface Wave Testing: Addressing Uncertainty using Open-Source Tools

Surface Wave Inversion Examples from Literature

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Summary Advice on Inversion

- Do not attempt to profile deeper than 1/2 to 1/3 of the maximum resolved wavelength.
- Do not attempt to resolve near-surface layers thinner than 1/2 to 1/3 of the minimum resolved wavelength.
- Using several trial layering parameterizations to investigate Vs model non-uniqueness. Cannot be emphasized enough!
- Using many thin, layers is not a good idea if strong V_S contrasts exist you will miss them.
- Do not permit unconstrained velocity reversals; you will get unrealistic fluctuations from high to low Vs.
- Attempt to quantify uncertainty/variability in V_S. At a minimum show some number of optimal models (e.g., best 100), although this is not rigorous it will give some qualitative estimate of uncertainty.

With these in mind, lets look at some examples from reports and literature.

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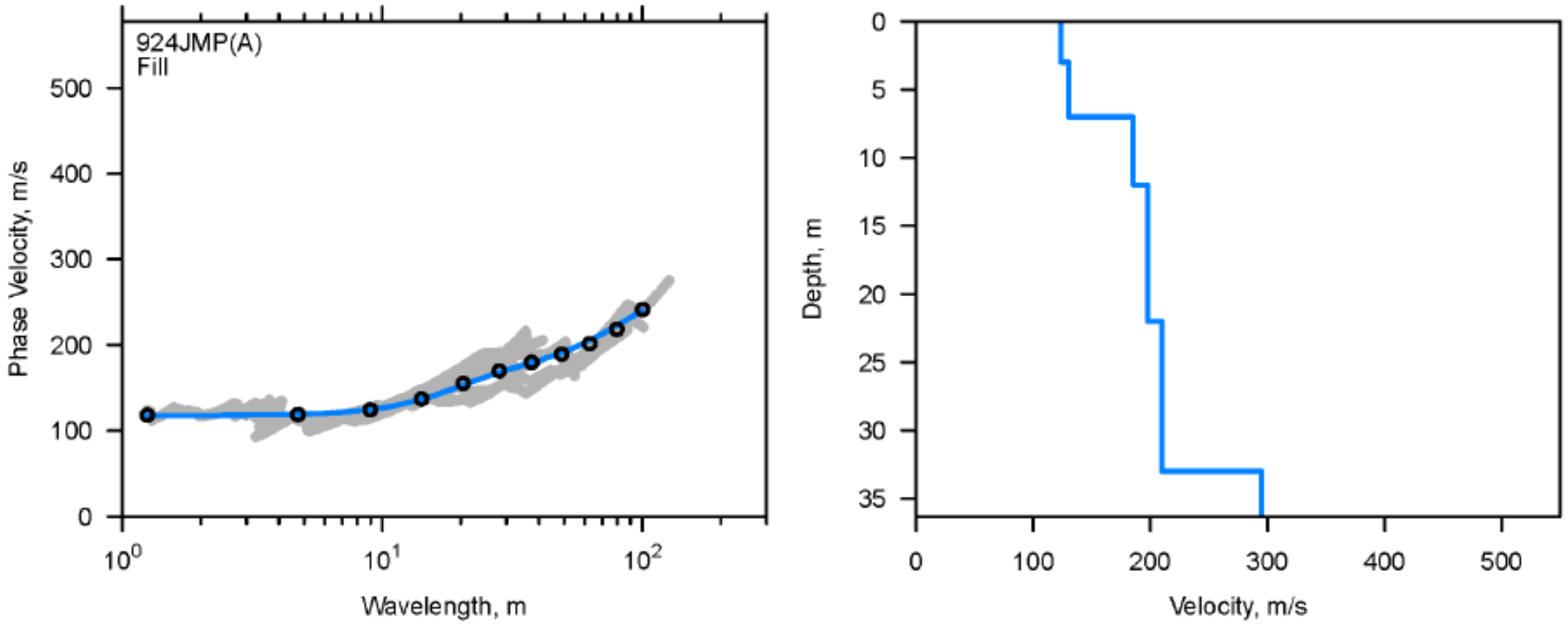
Example #1

USGS Open File Report 2014



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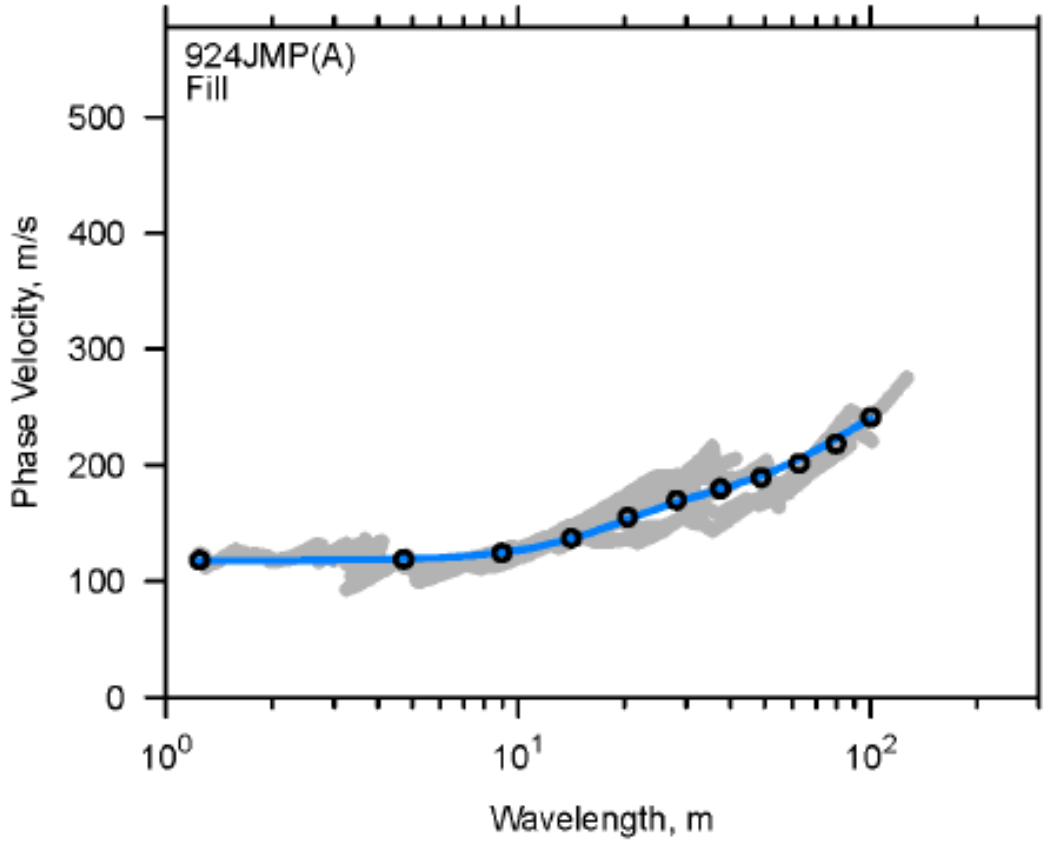
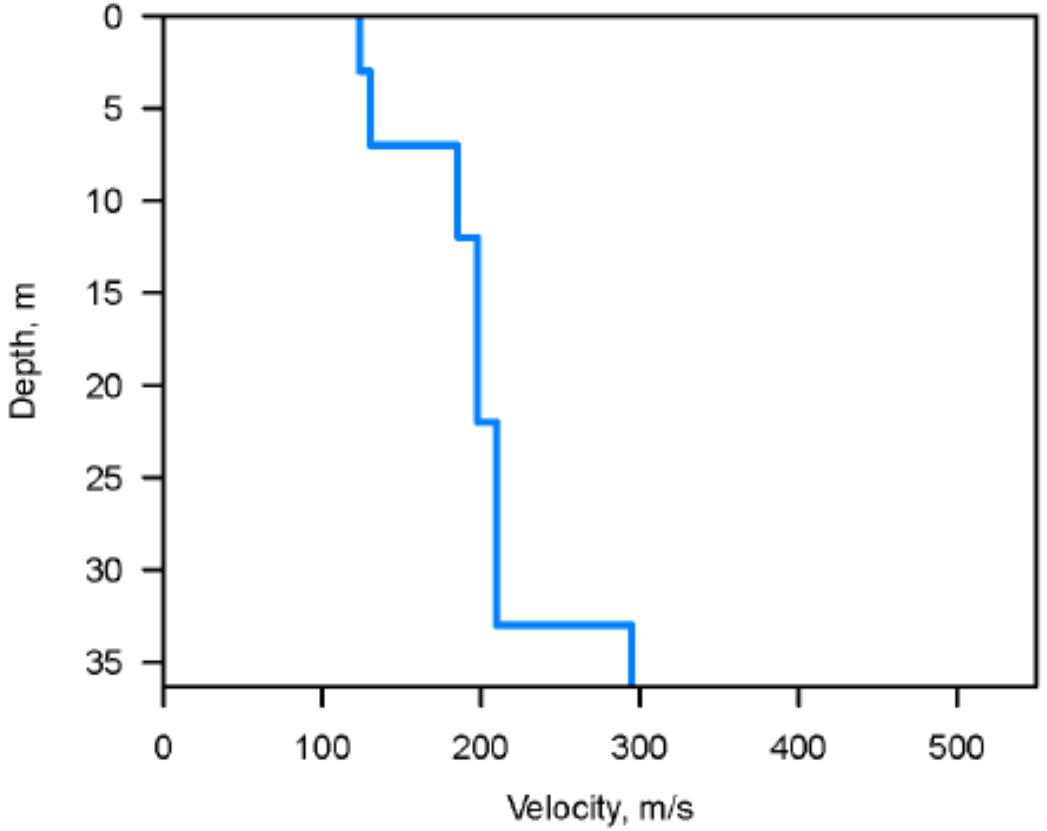
Example #1

USGS Open File Report 2014

Fit to the data is OK
$\lambda_{min} = 1.2\ m$ thinnest layer 2 m is OK
$\lambda_{max} = 100\ m$ maximum depth of 37 m is OK
No sign of reversals so OK
No consideration of uncertainty.
Summary: Not bad, would be better if considered uncertainty.





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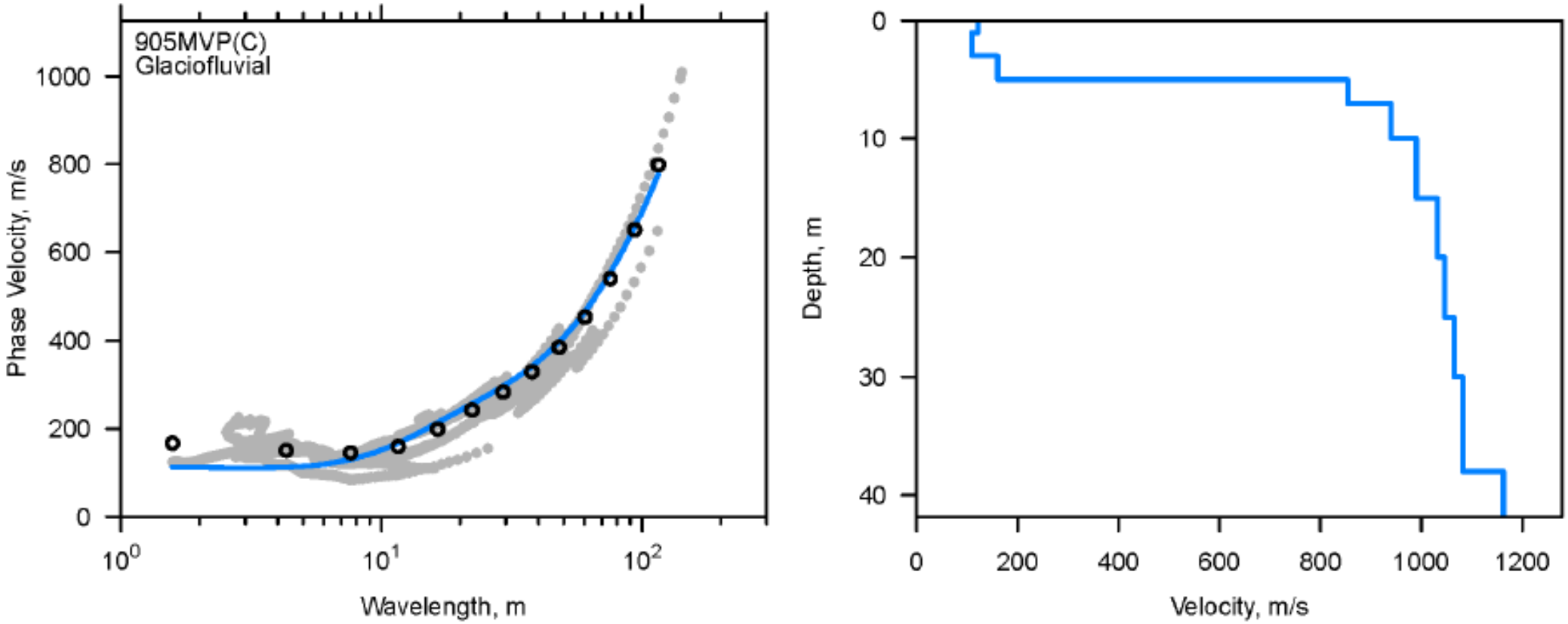
Example #2

USGS Open File Report 2014



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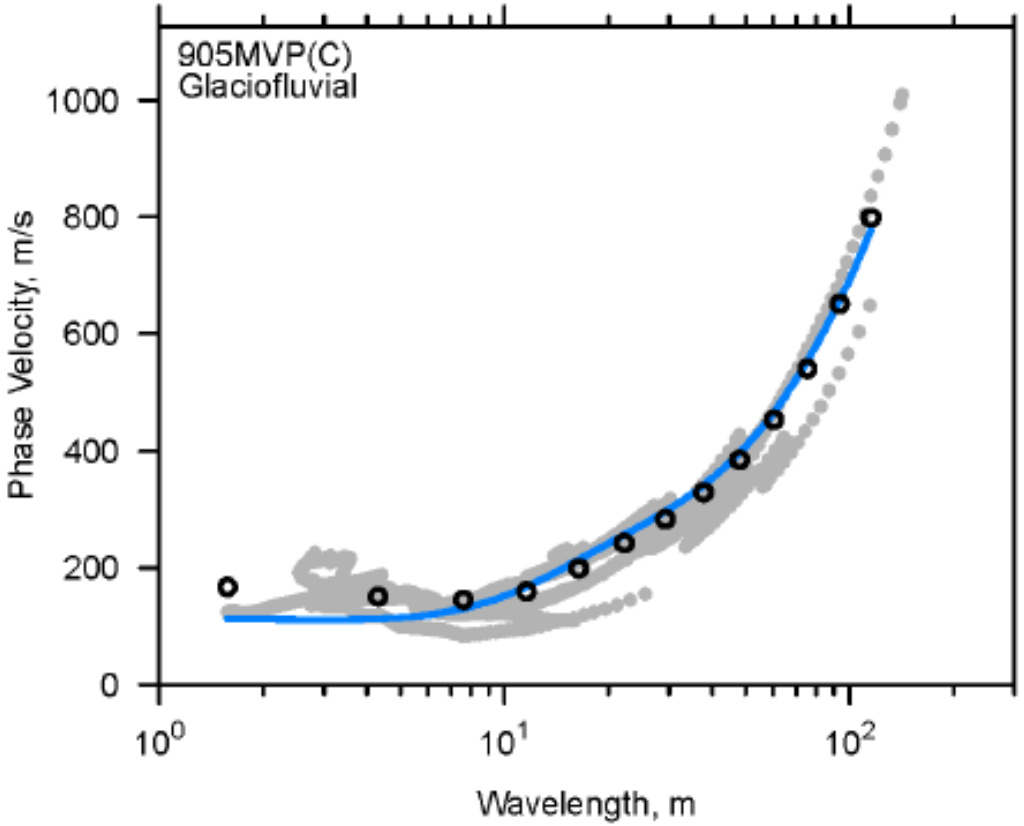
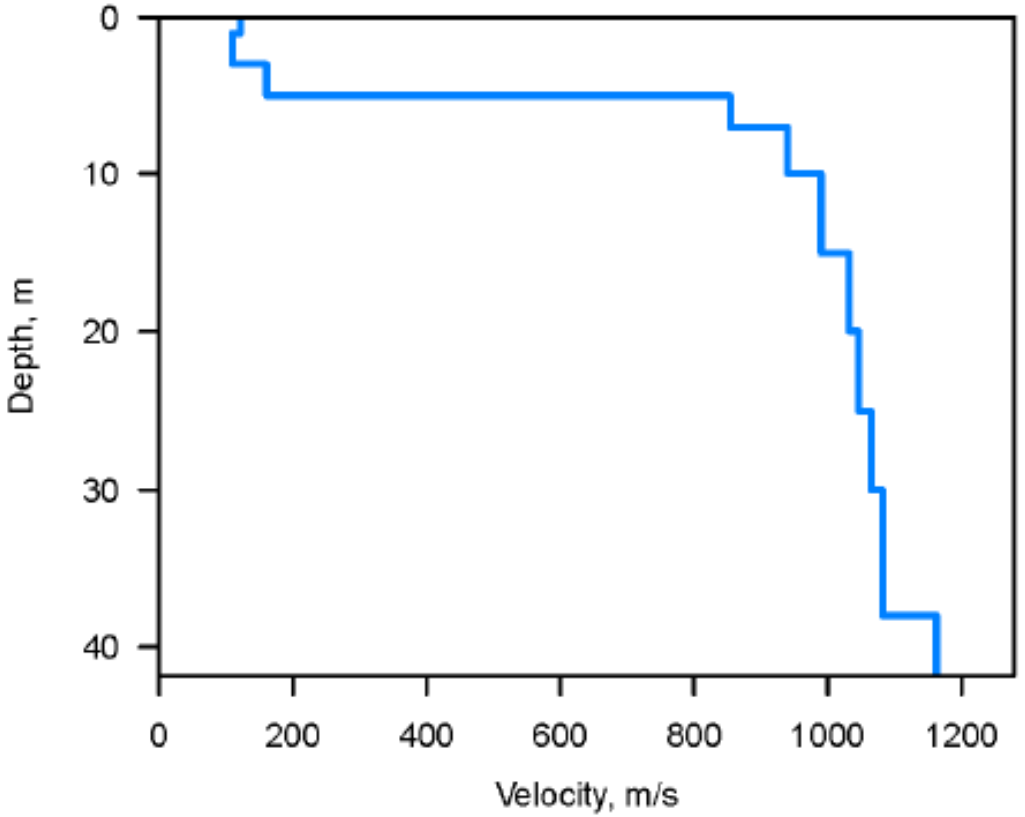
Example #2

USGS Open File Report 2014

Fit to the data could be better at short wavelengths
$\lambda_{min} = 1.3\ m$ thinnest layer 1 m is OK
$\lambda_{max} = 100\ m$ maximum depth of 42 m is OK
Might be missing a reversal.
No consideration of uncertainty
Summary: Should be refined further





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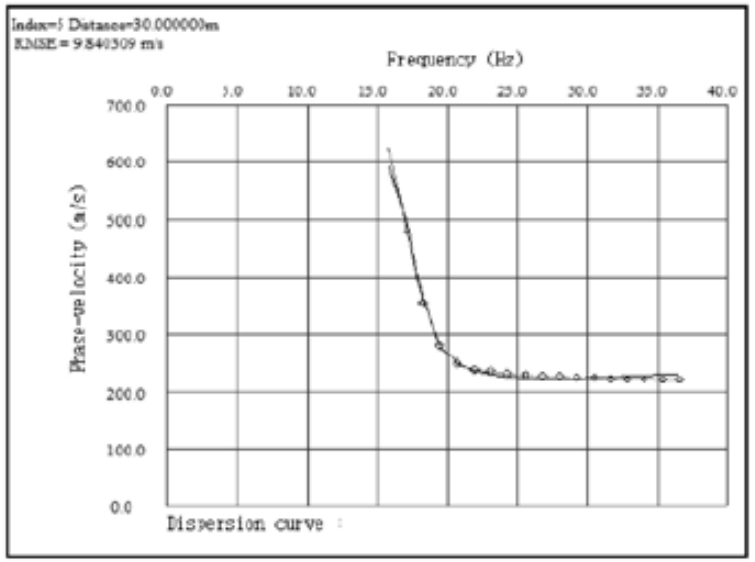
Example #3

2D MASW Journal Paper

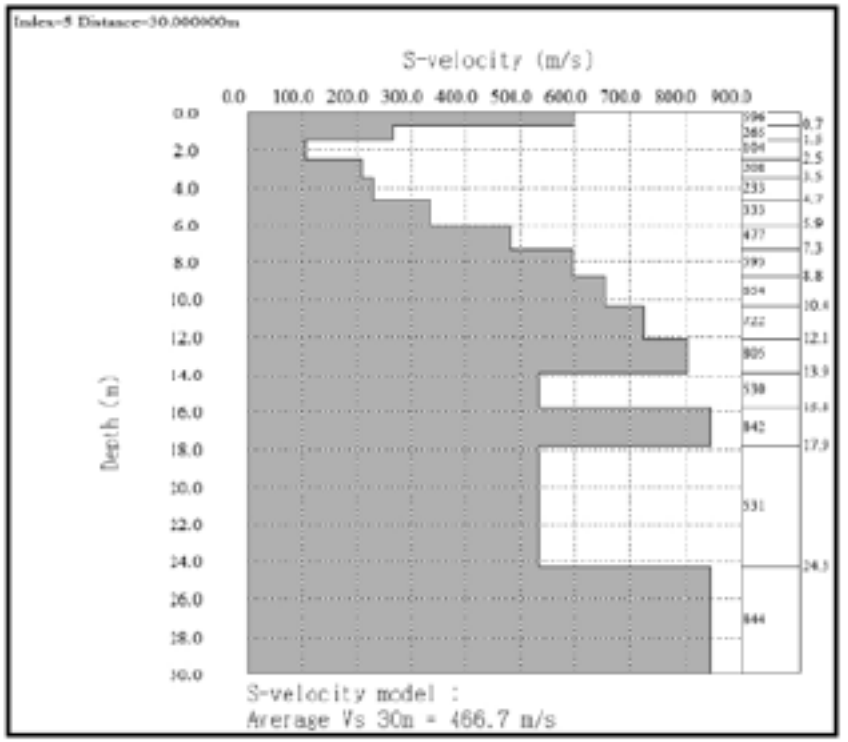
J. Ind. Geophys. Union (May 2018)
v.22, no.3, pp: 265-278

Site characterisation using Multi-channel Analysis of Surface Waves at various locations in Kumaon Himalayas, India

Anand Joshi*[1] and Parul Bhardwaj[2]
[1]Department of Earth Science, Indian Institute of Technology Roorkee, Roorkee, India 247667
[2]KDMIPE, Oil & Natural Gas Corporation Ltd., Dehradun, India 248195
*Corresponding Author: parul1611pandit@gmail.com



Dispersion Curve



Final S-Velocity Model

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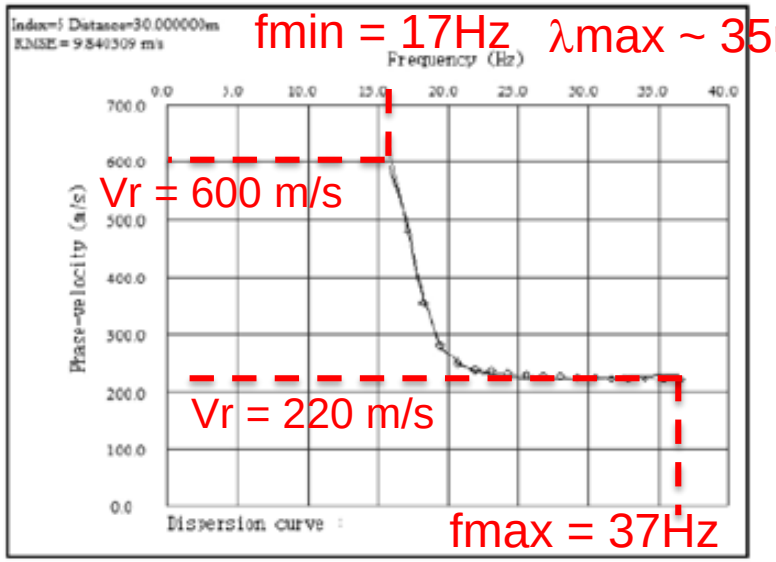
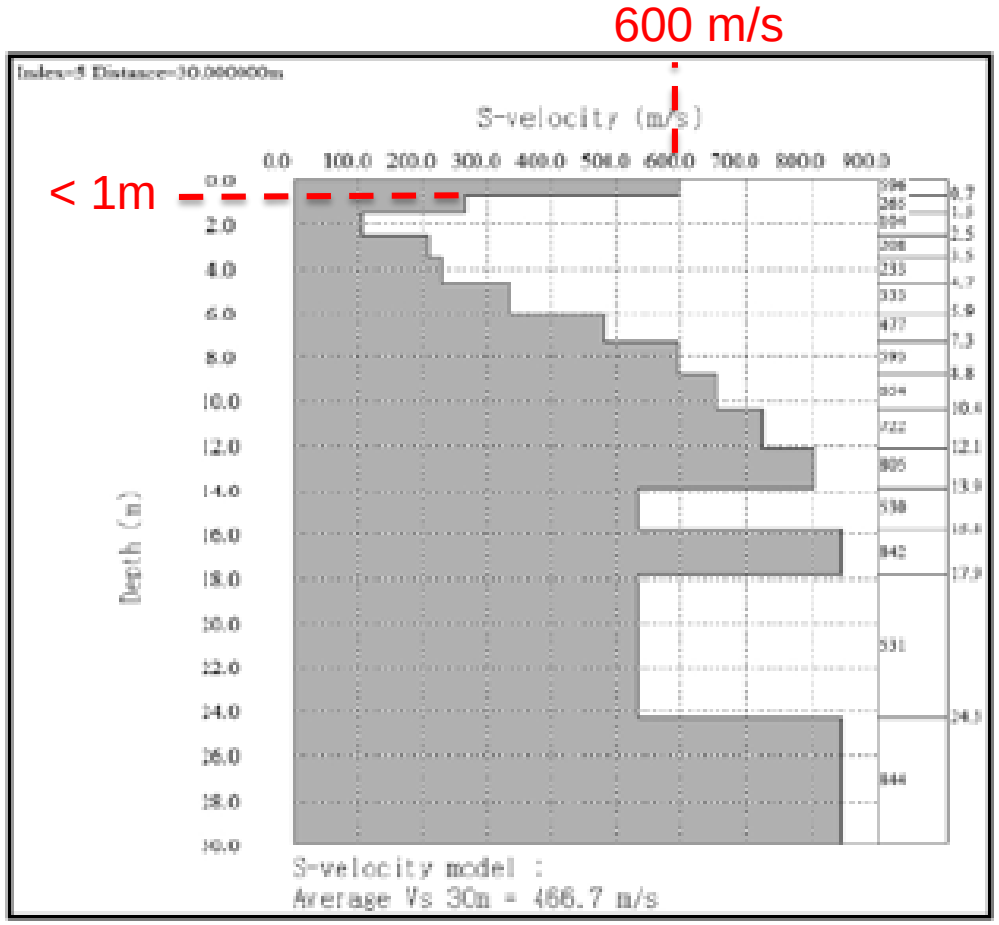
Example #3

2D MASW Journal Paper



Dispersion Curve



Final S-Velocity Model

1) Top V_S layer is too thin relative to λmin ~ 6m
2) Top layer is too fast relative to V_r = 220 m/s
3) DC shows no evidence of LVL's present in V_S
4) Max 30m depth of V_S too great relative to λmax ~ 35m

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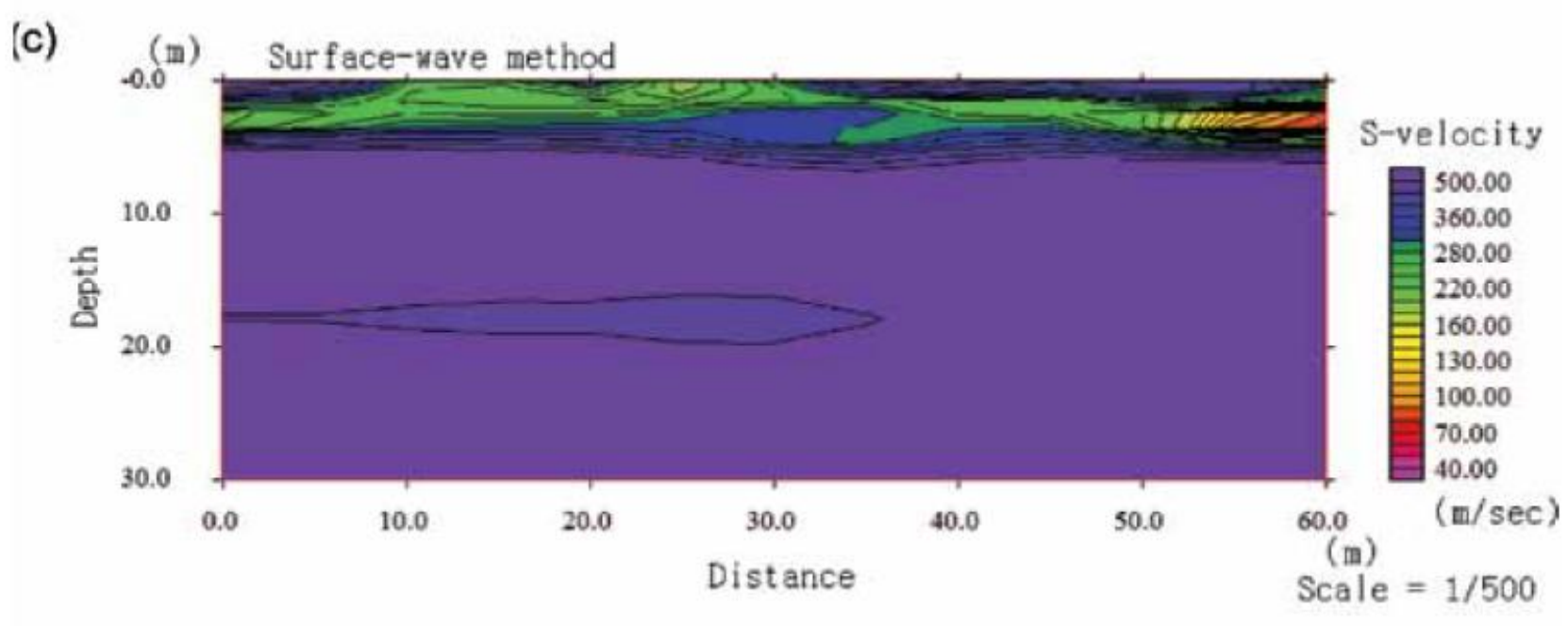
Example #3

2D MASW Journal Paper

Now, make this junk look pretty by inverting a bunch of these bad 1D Vs profiles side-by-side and then contour them together to create a “2D” image.



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Example #4

GSC Surface Wave Guidelines

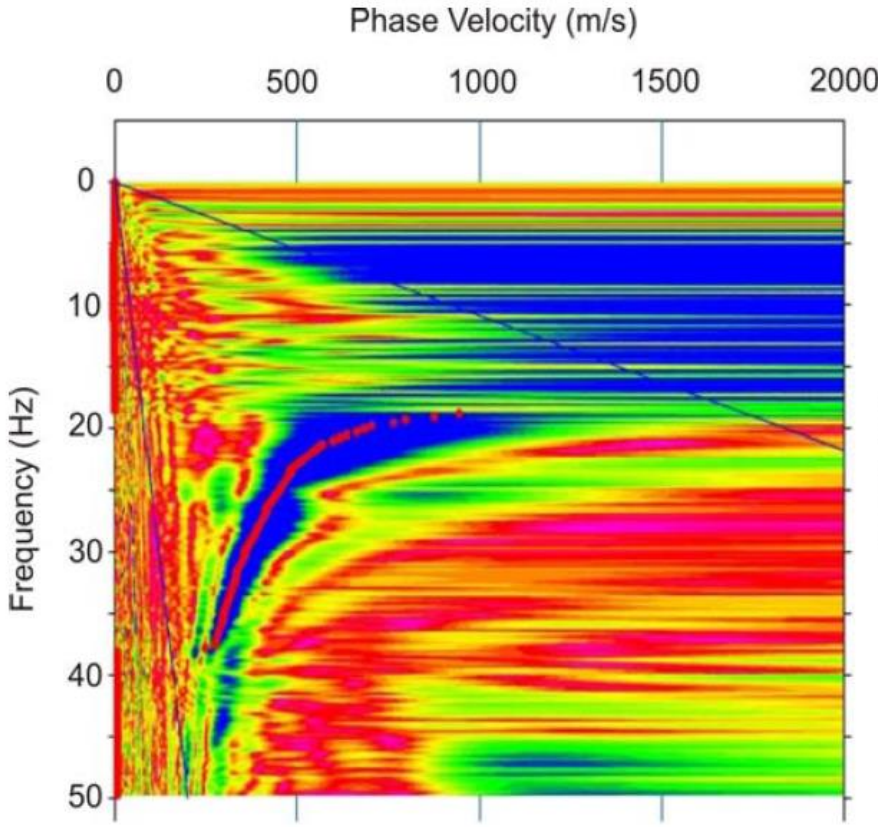

Figure 2.2.3-3: Field data example of a dispersion curve with identification of the fundamental mode (red dots) (left) and resulting shear wave velocity profile (right).

Experimental λ_{min} =

Experimental λ_{max} =

Inverted Vs_{min} ~

Inverted Vs_{max} >

LVL layers? =

Quality of picks at low frequencies?

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Example #4

GSC Surface Wave Guidelines

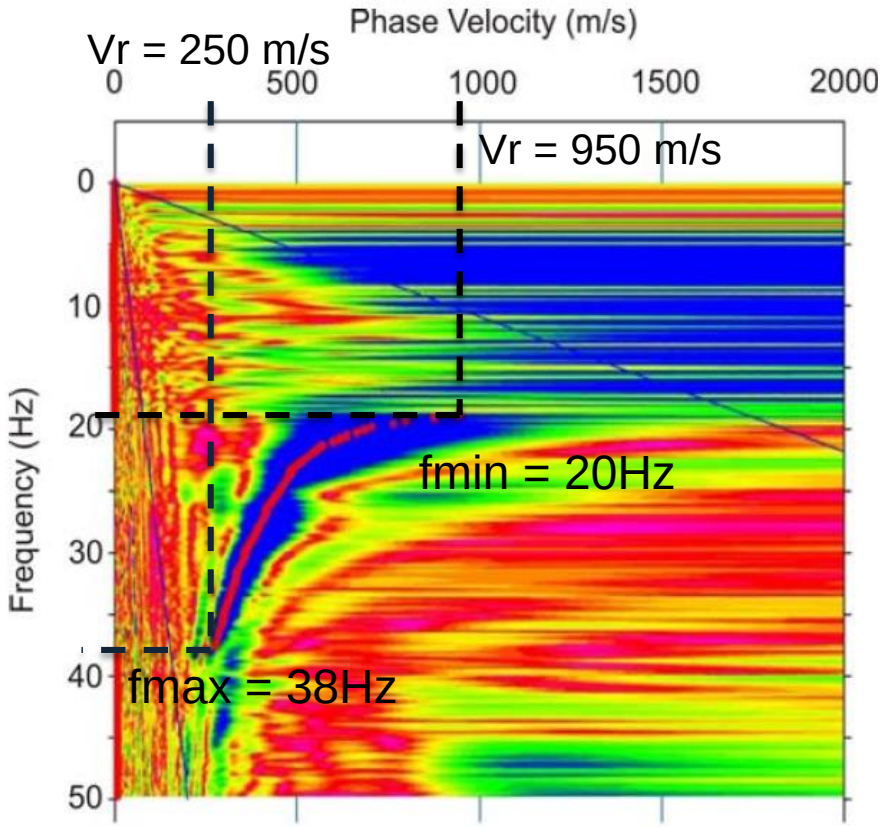

Figure 2.2.3-3: Field data example of a dispersion curve with identification of the fundamental mode (red dots) (left) and resulting shear wave velocity profile (right).

Experimental λ_{min} = 6.5m

Experimental λ_{max} = 47.5m

Inverted Vs_{min} ~ 275 m/s

Inverted Vs_{max} > 1050 m/s

LVL layers? = No

Quality of picks at low frequencies?

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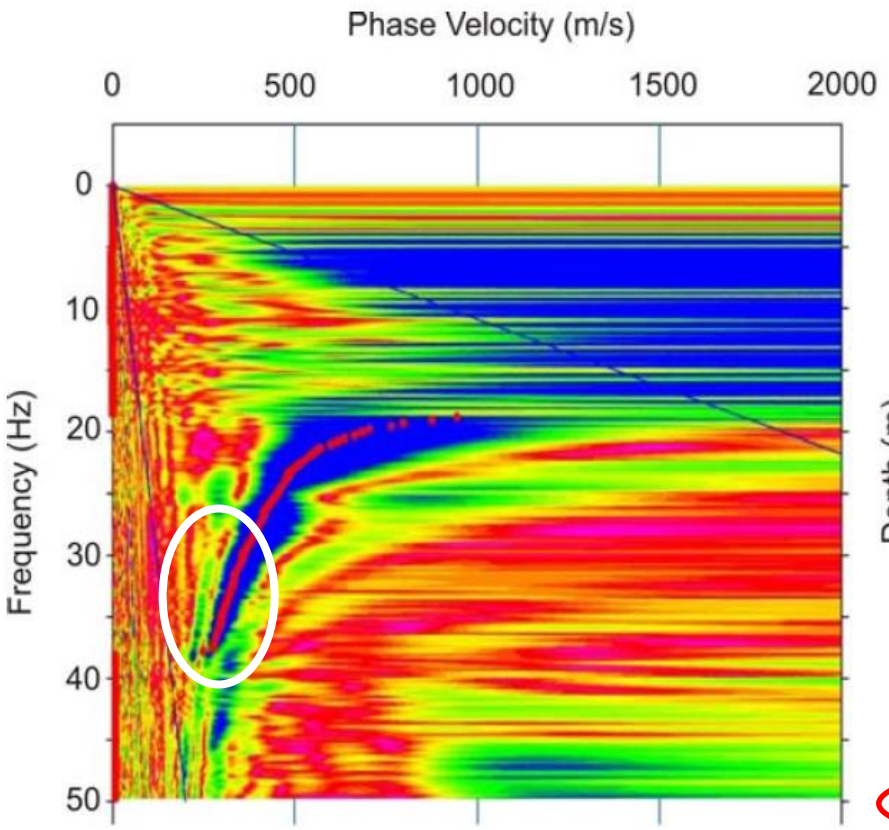
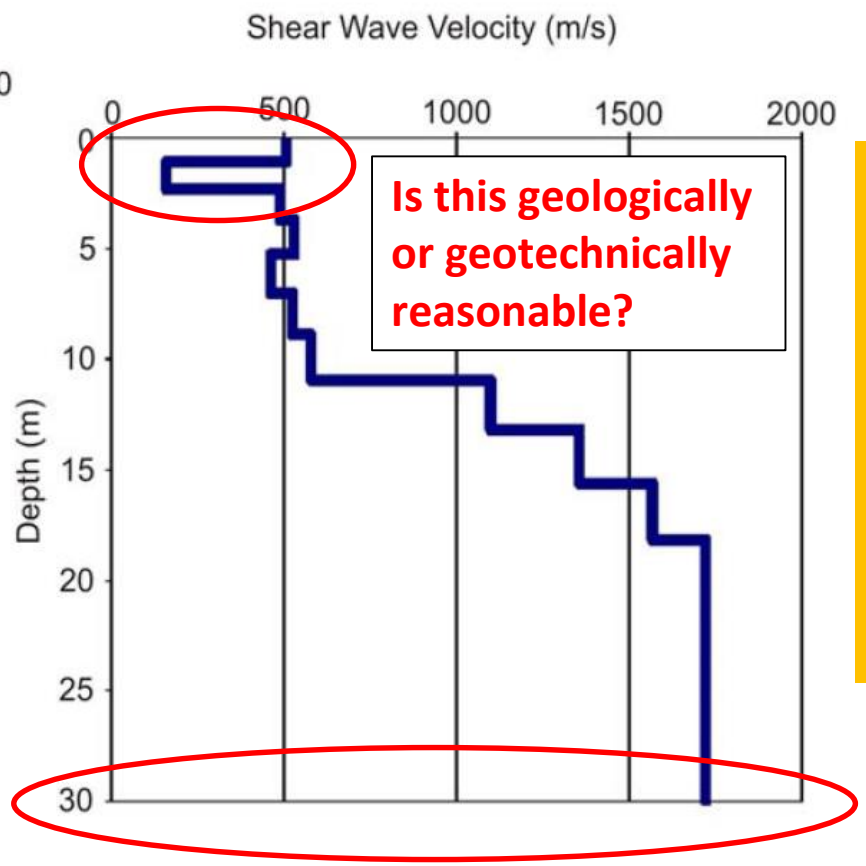
Example #4

GSC Surface Wave Guidelines

No evidence of inversion/LVL in dispersion data





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Experimental λ_{min} = 6.5m

Experimental λ_{max} = 47.5m

Inverted Vs_{min} ~ 275 m/s

Inverted Vs_{max} > 1050 m/s

LVL layers? = No

Quality of picks at low frequencies?

Should they have extended the Vs profile to 30m?

Limiting it to λmax /2 = 47.5m/2 = 24m would have been better.

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Example #5

Near Surface Geophysics (2018)

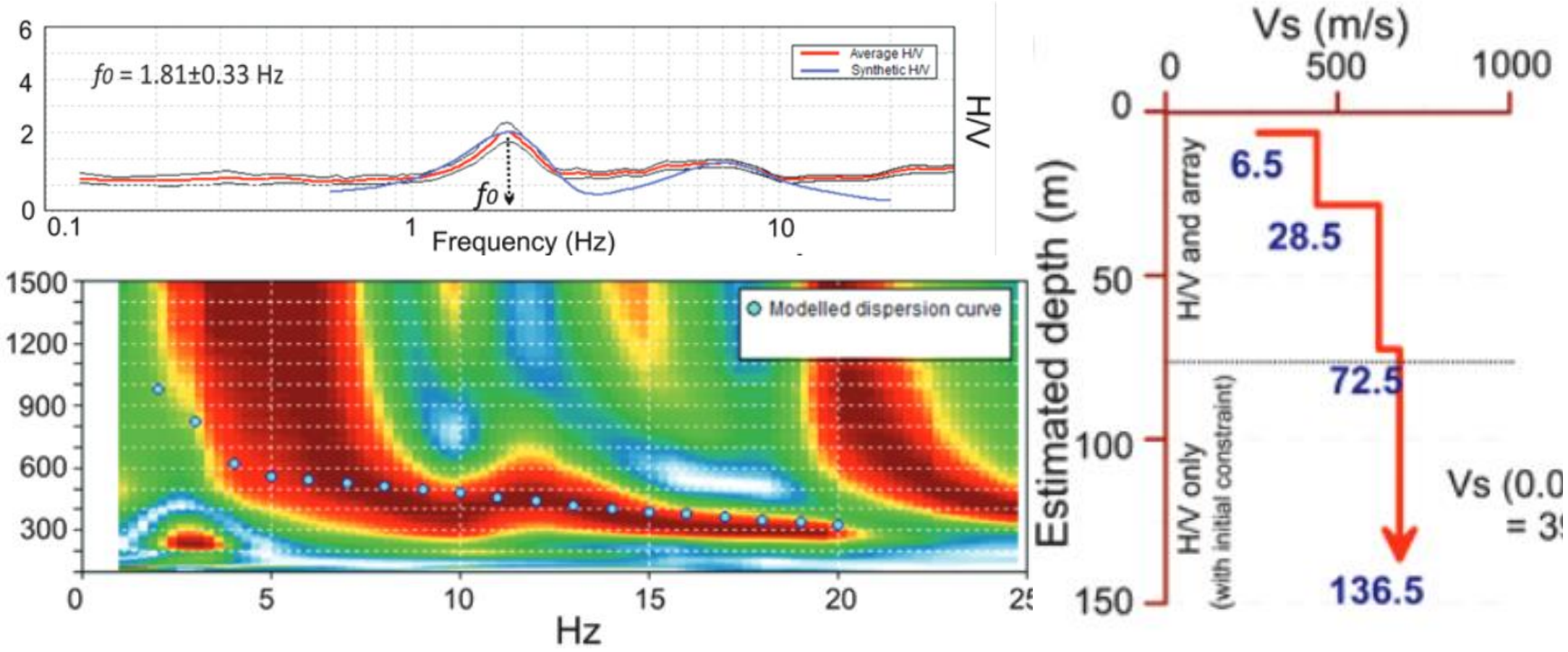

Figure 5 Joint-fit modelling procedure with H/V and DC, a) synthetic HVSR (blue colour) and the experimental average HVSR (red colour), b) phase velocity spectra obtained at a site characterised by deep bedrock (136 m), which produced a resonance peak at 1.81 Hz. The maximum exploring wavelength calculated from the array is 600 m/s/4 Hz = 150 m and half of the wavelength is the penetration depth, i.e., 75 m, c) beyond ~75-m depth, the deeper profile is obtained from the inversion of the H/V curve only, d) shows detailed information on the velocity model derived by both the methods, and e) lithology from the borehole data obtained at the HVSR site (source: Irrigation and Public Health, Govt. of Himachal Pradesh).

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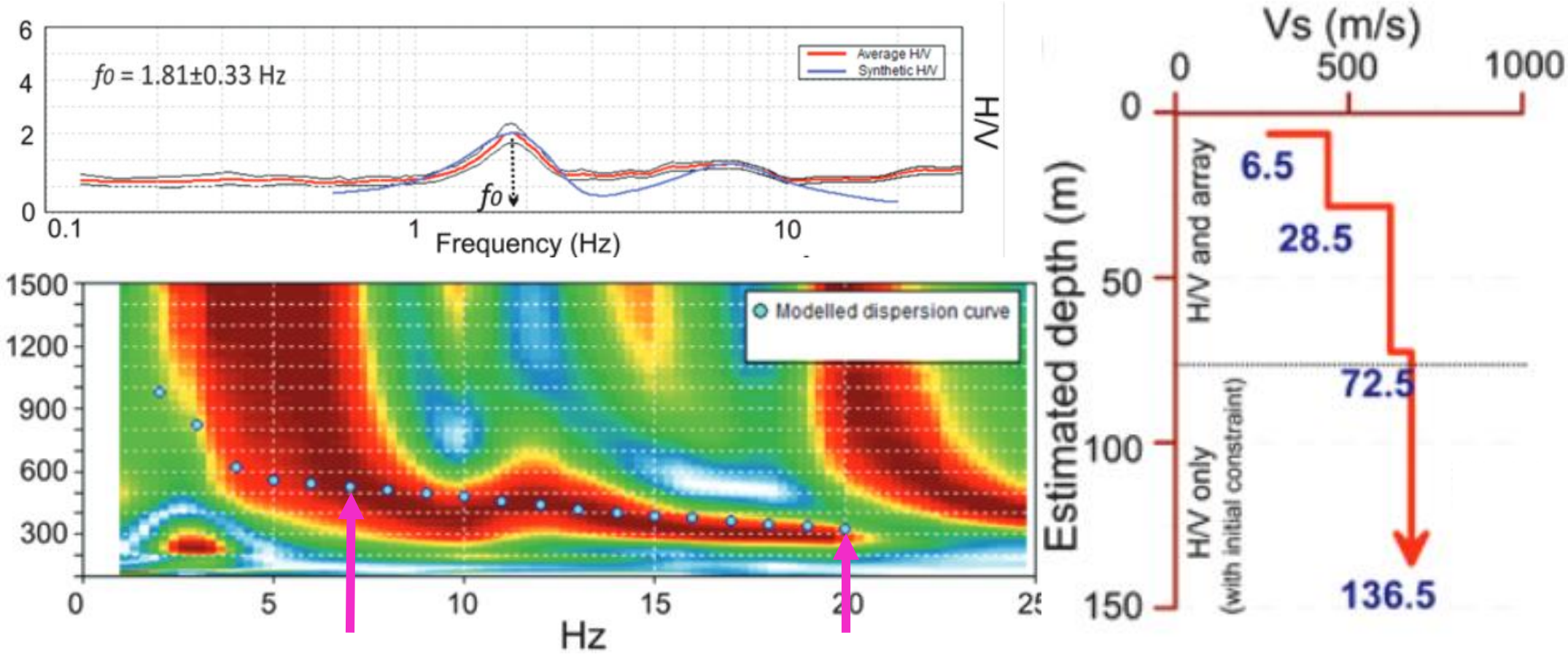
Example #5

Near Surface Geophysics (2018)

Measured and inverted dispersion fit is NG
$\lambda_{min} = 15\ m$ thinnest layer 6.5 m is OK
$\lambda_{max} = 85\ m$ (?) maximum depth of 136 m is NG
Reversal is missing NG.
Summary: Highly questionable results.



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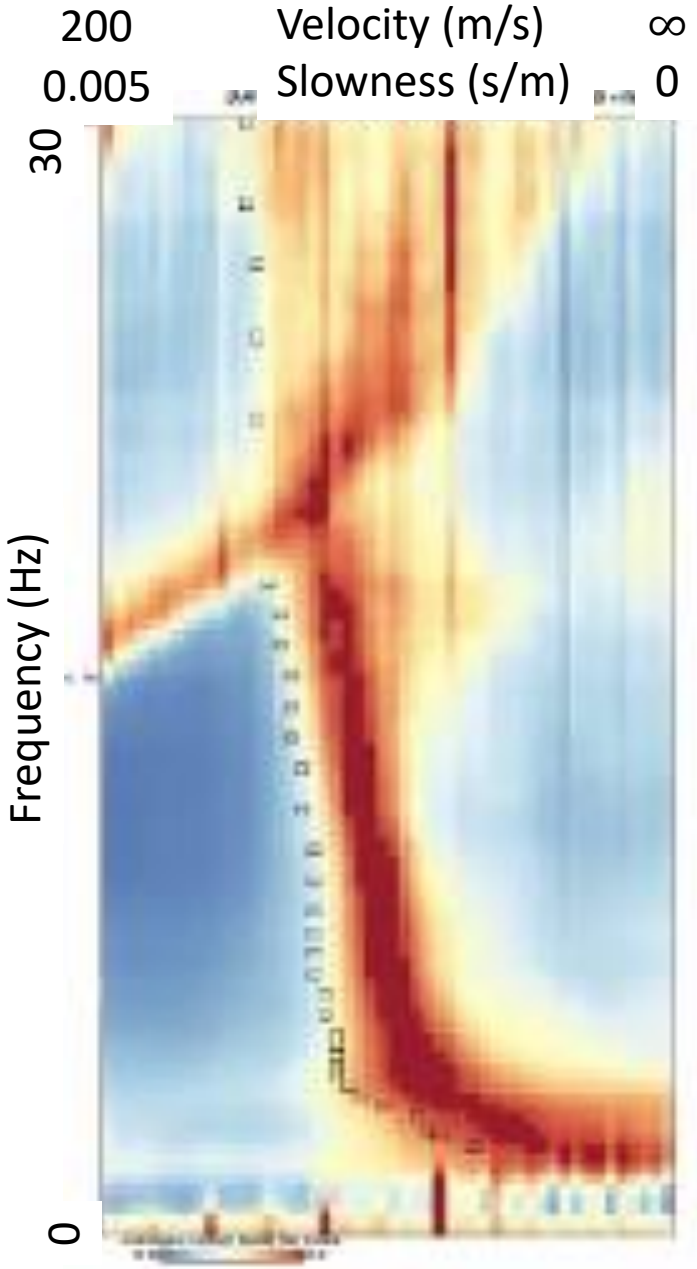
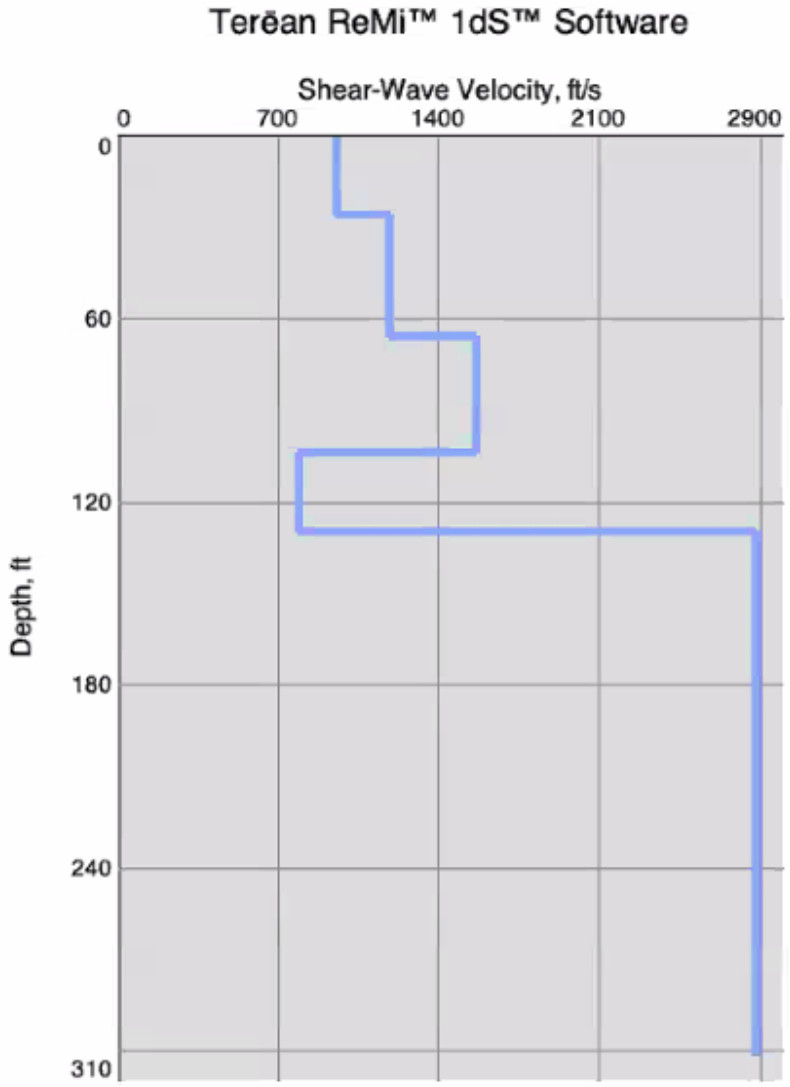
Example #6

ReMI Results Louie (2024)





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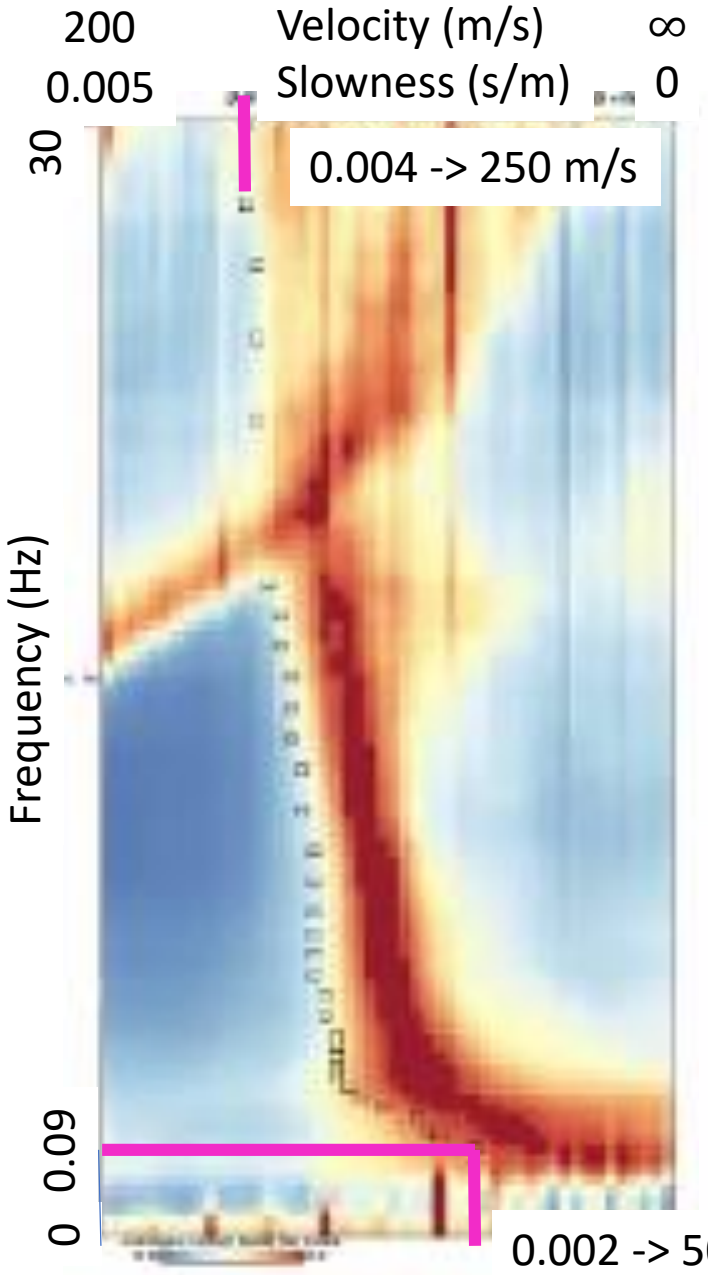
VIRGINIA TECH

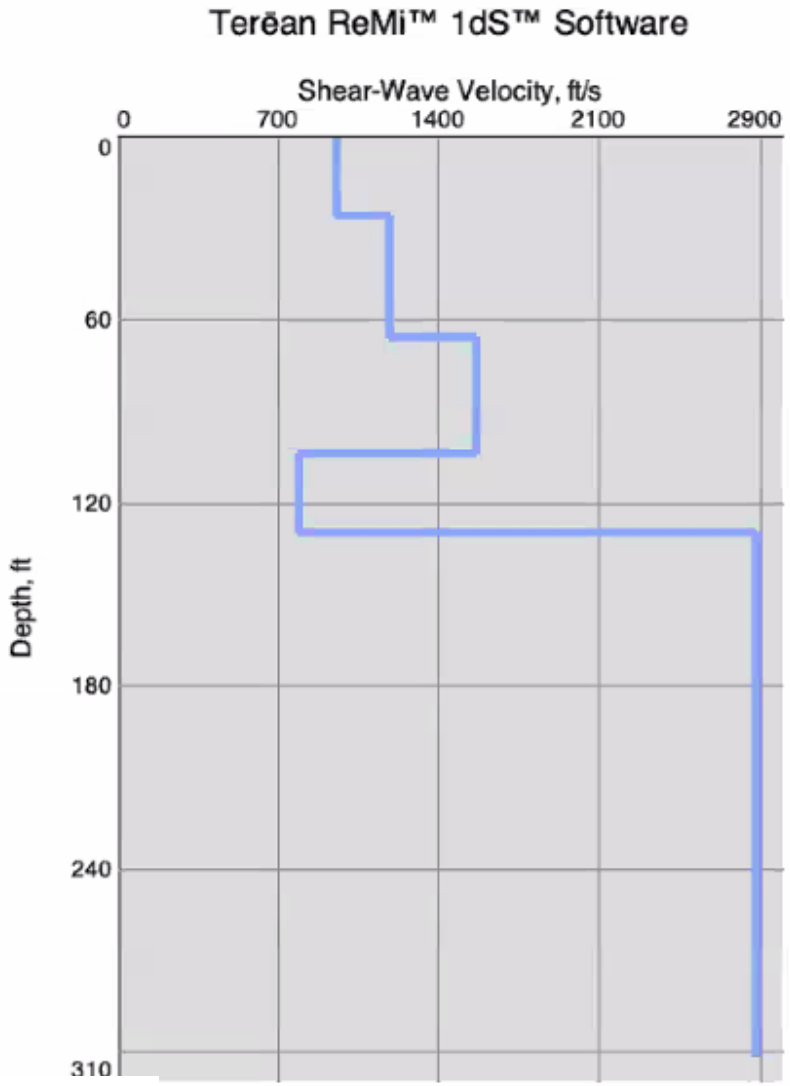
UtahStateUniversity

Example #6

ReMI Results Louie (2024)

No measured and inverted dispersion NG
Picking at low frequencies (?)
$\lambda_{min} = 8\ m$ thinnest layer 10 m is OK
$\lambda_{max} = 5000\ m$ (?)
Reversal is not supported in data
Summary: Highly questionable results.





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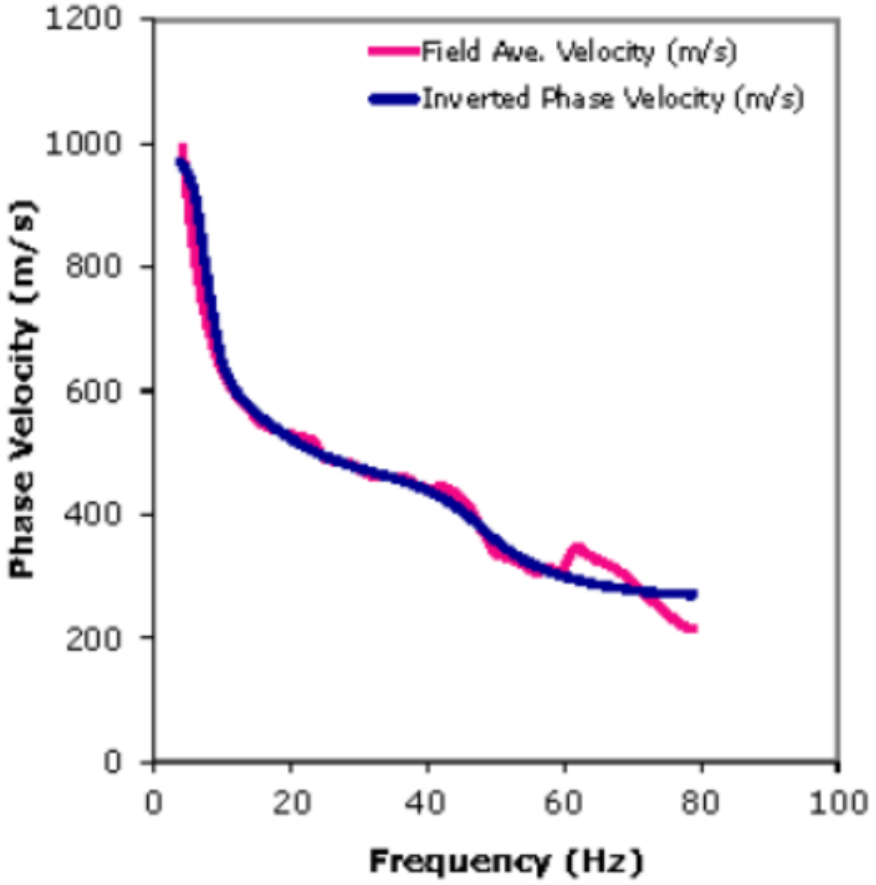
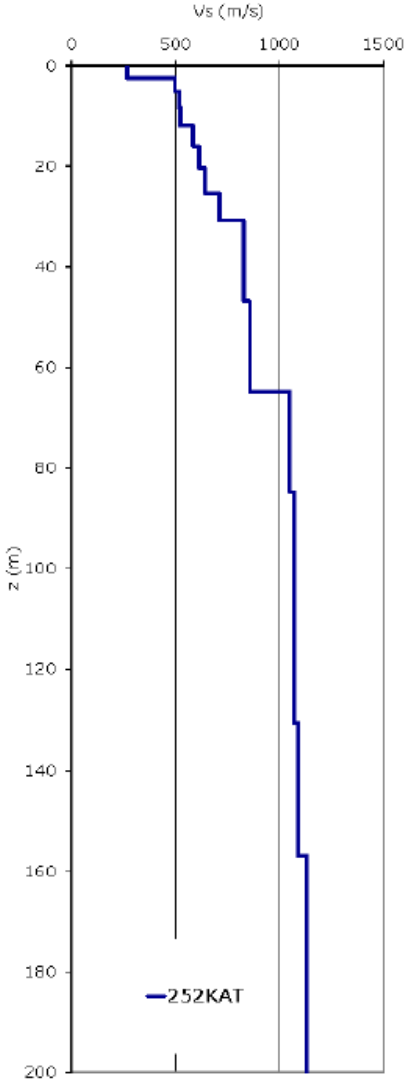
Example #7

USGS Open File Report 2014





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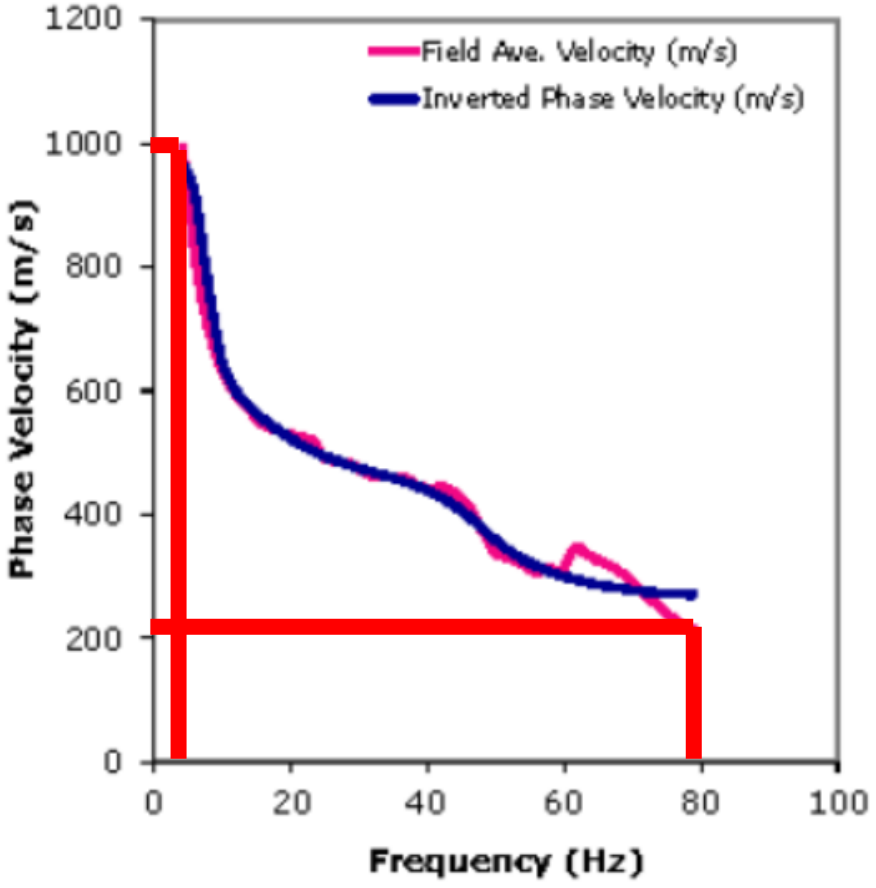
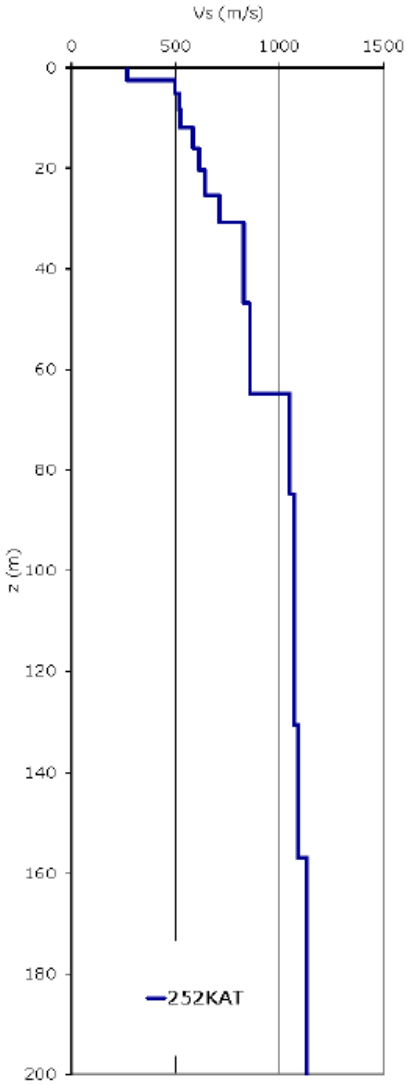
Example #7

USGS Open File Report 2014





Measured and inverted dispersion fit is OK (Could be better)

$\lambda_{min} = 2.5\ m$ thinnest layer 2 m is OK

$\lambda_{max} = 250\ m$ maximum depth of 200 m is NG

No reversals appears reasonable.

Summary: Would want to refine near surface structure and cut to depth to < 125 m.

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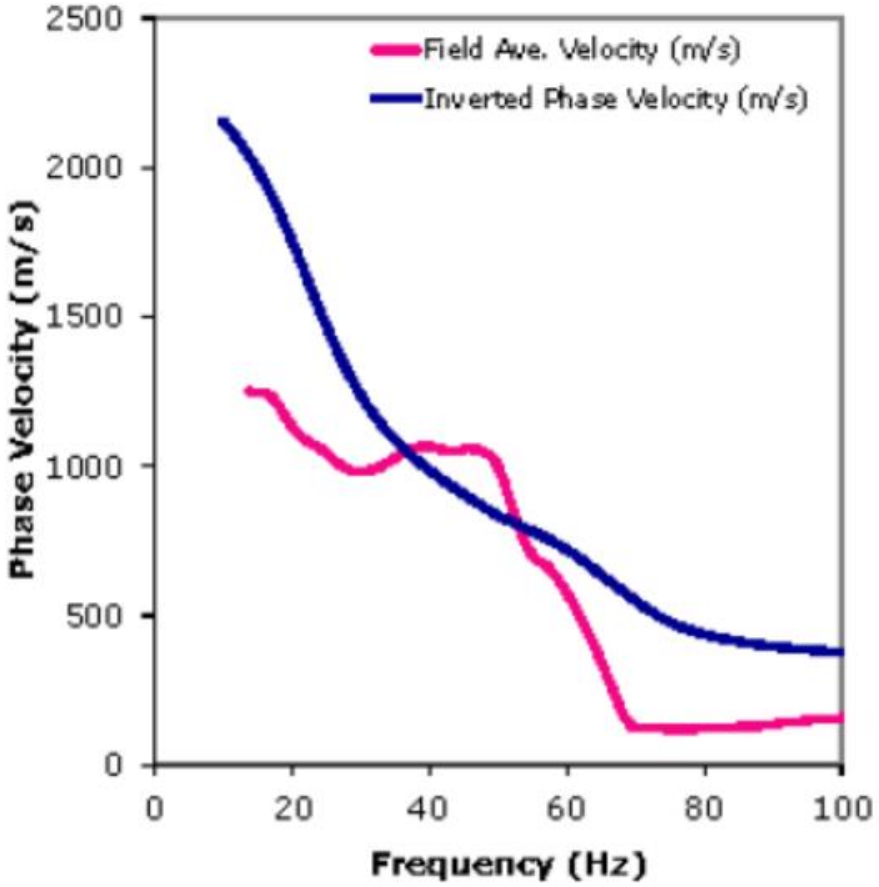
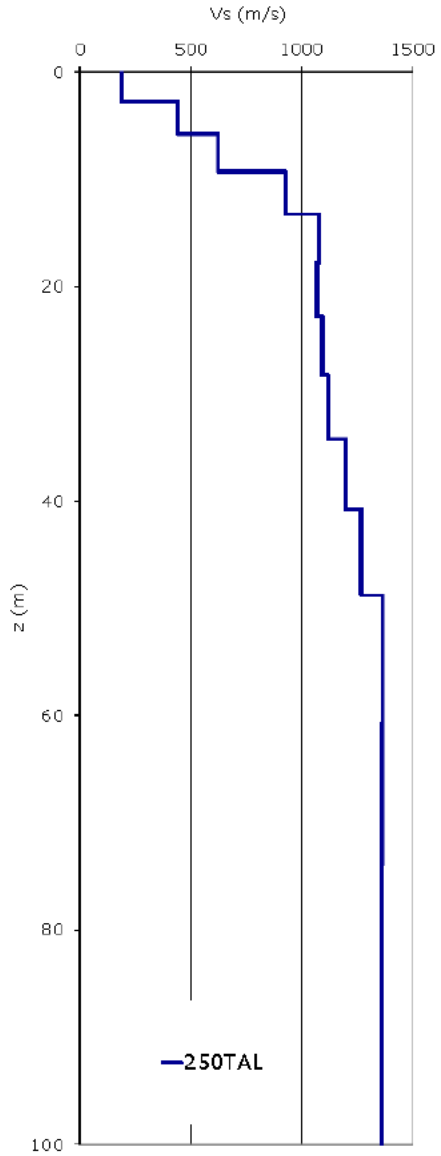
Example #8

USGS Open File Report 2014





Same report as previous

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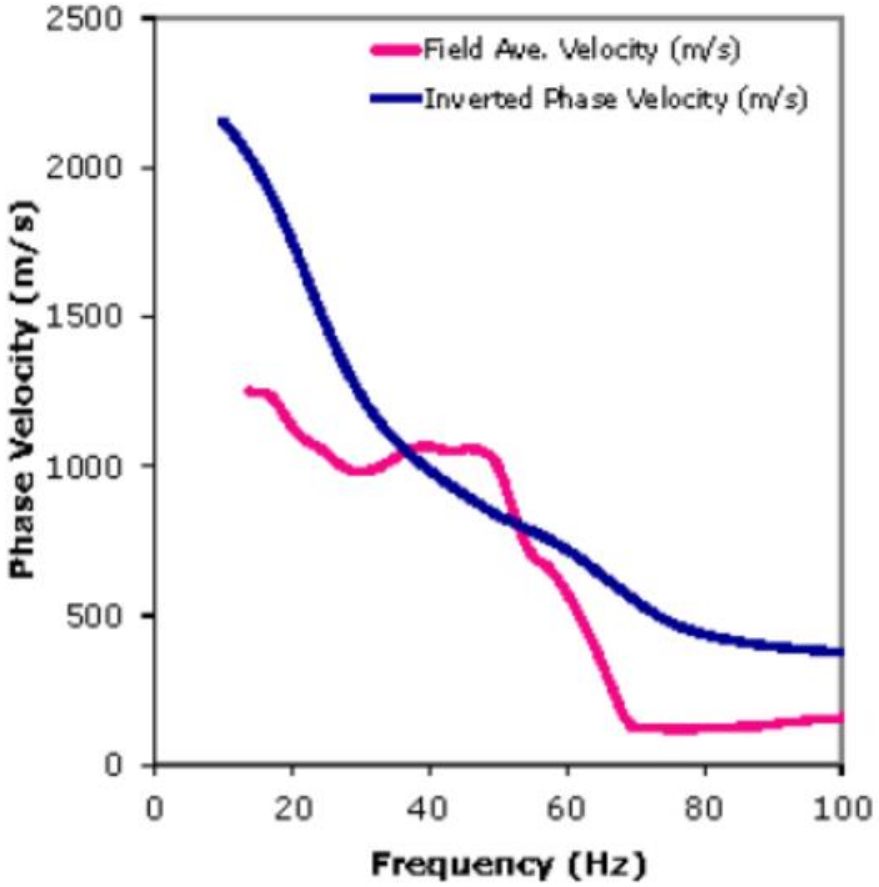
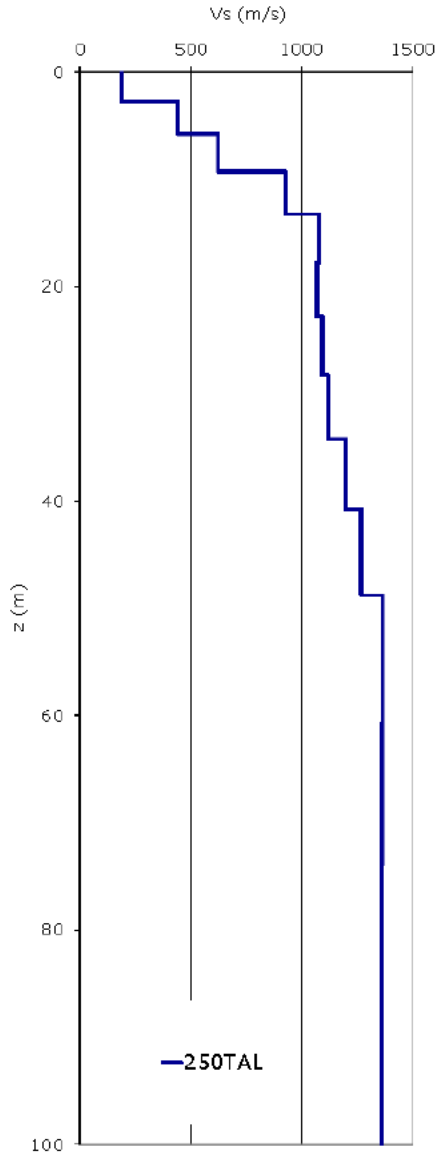
Example #8

USGS Open File Report 2014



Same report as previous



If measured and inverted dispersion data do not fit, do not trust the Vs profile!

Not just this site …

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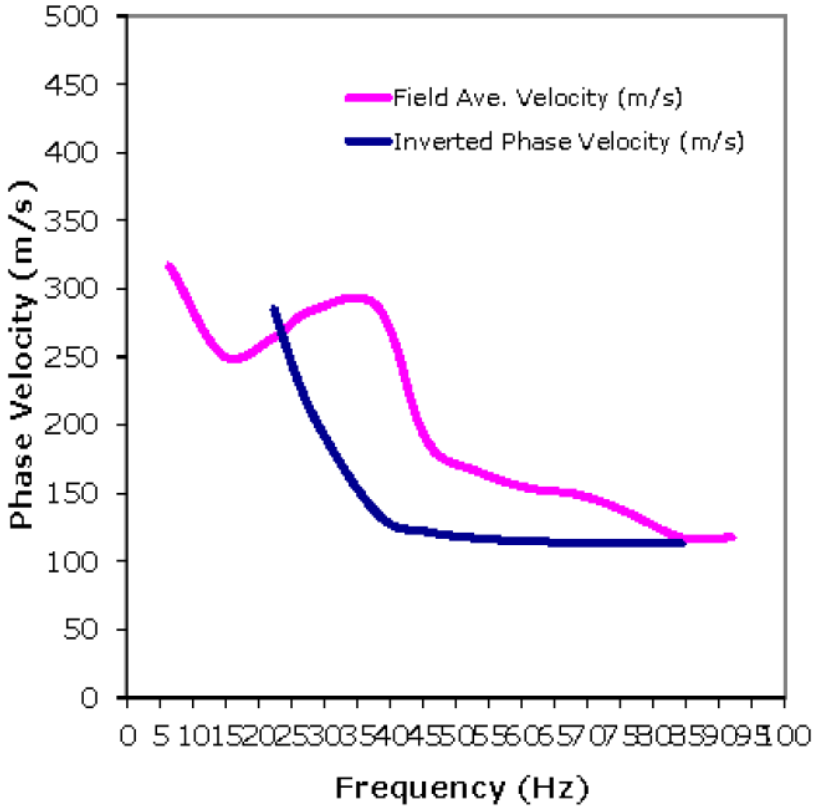
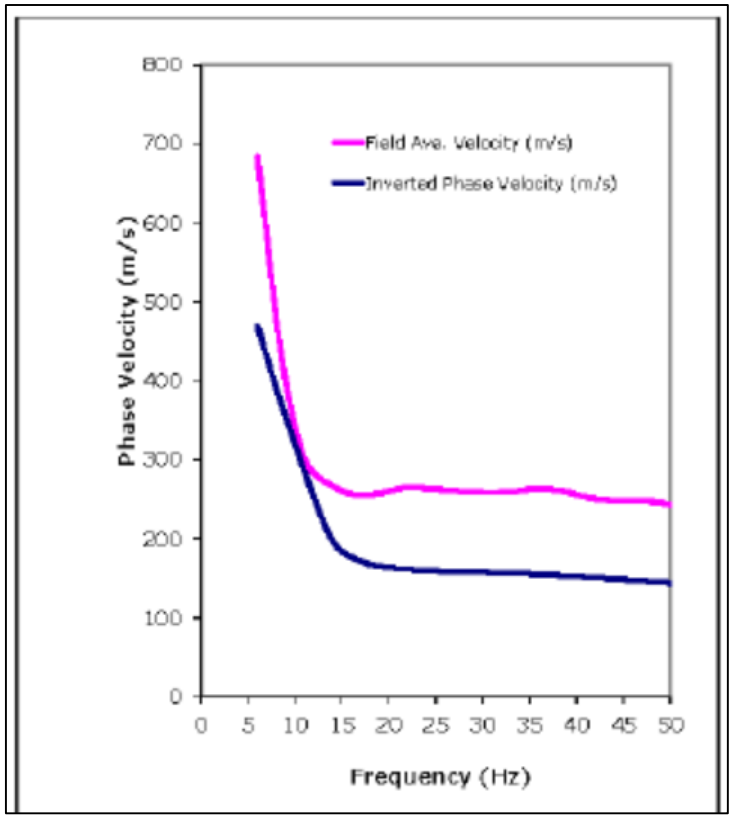
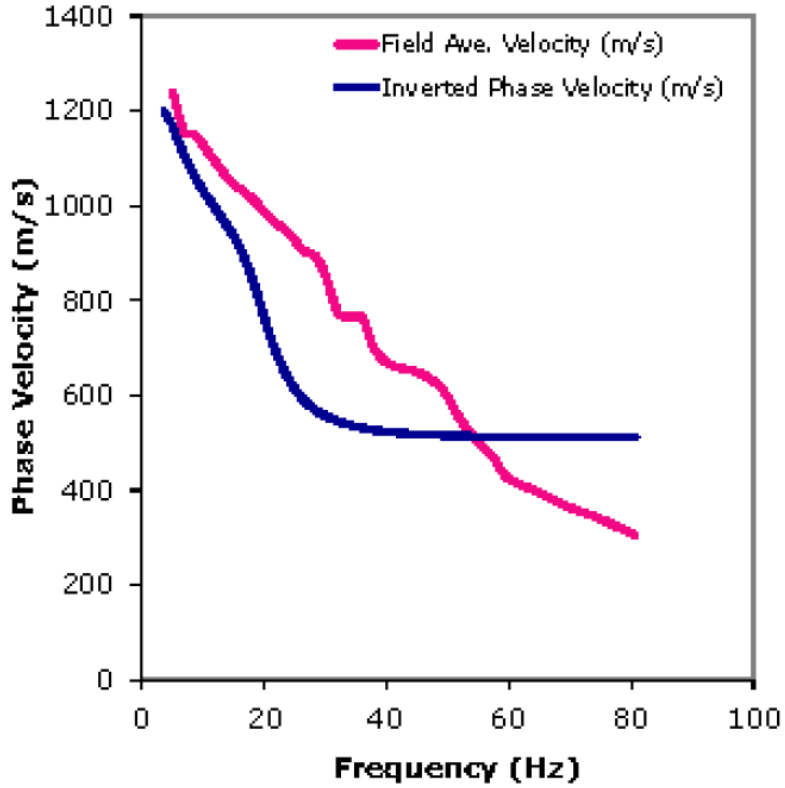
Examples #9, #10, and #11

Example: USGS Open File Report 2014

Same report as before, other sites!







This emphasizes the important of showing the experimental and theoretical data on the same plot; be skeptical of the results you are provided!

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J.P. Vantassel

Summary Advice on Inversion

- Do not attempt to profile deeper than 1/2 to 1/3 of the maximum resolved wavelength.
- Do not attempt to resolve near-surface layers thinner than 1/2 to 1/3 of the minimum resolved wavelength.
- Using several trial layering parameterizations to investigate Vs model non-uniqueness. Cannot be emphasized enough!
- Using many thin, layers is not a good idea if strong V_S contrasts exist you will miss them.
- Do not permit unconstrained velocity reversals; you will get unrealistic fluctuations from high to low Vs.
- Attempt to quantify uncertainty/variability in V_S. At a minimum show some number of optimal models (e.g., best 100), although this is not rigorous it will give some qualitative estimate of uncertainty.

Keep these best practices in mind when producing reports.

Be critical of results you receive.

B.R. Cox,
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