Progetto S4 INGV

Task 3

Outline

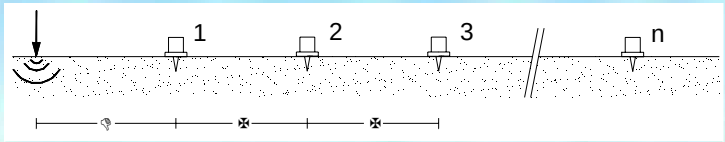
- Surface wave methods
- Comparison SWM-borehole methods
- Consequences of non-uniqueness
- Blind test EGS 2006
- Final remarks and floor discussion

	Surface wave methods
Advantages	Works also where soft and stiff layers alternate Reduced testing time on site Average properties (dynamic behaviour of the whole soil deposit) Resolution shallow layers
Disadvantages	Inverse problem 1D Model with plane and parallel layers Resolution decreases with depth Uncertainty in bedrock localization

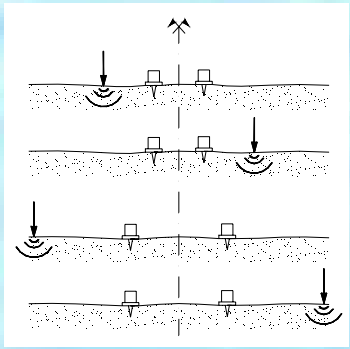
SWM techniques

Active methods

Multistation
(f-k, τ-p, ...)

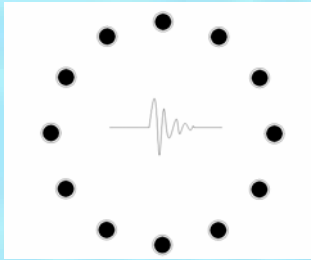


Two-station (SASW)

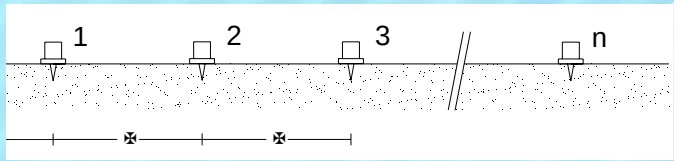


Passive methods

Spatial Array
SPAC, FK (FBDF, Capon, ...), ...



Linear array (ReMi)

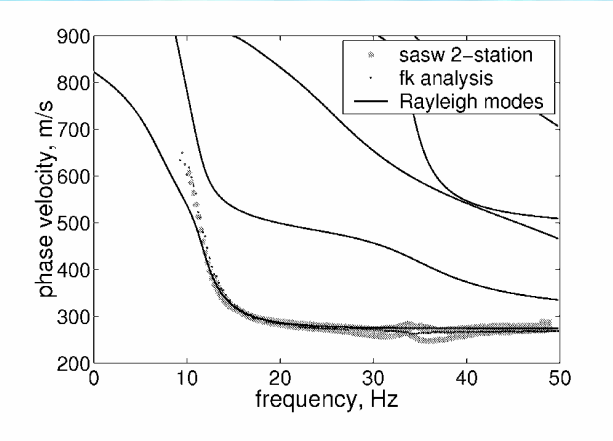


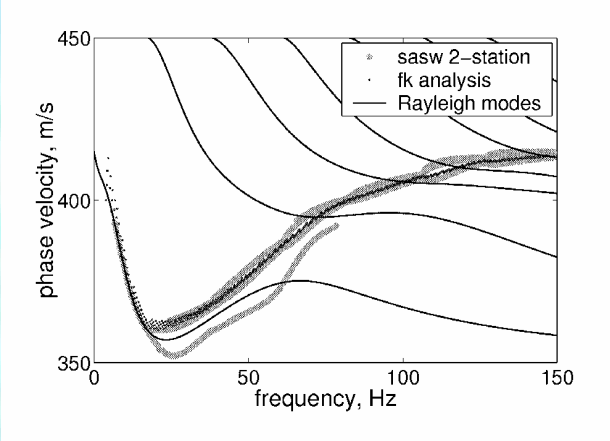
?

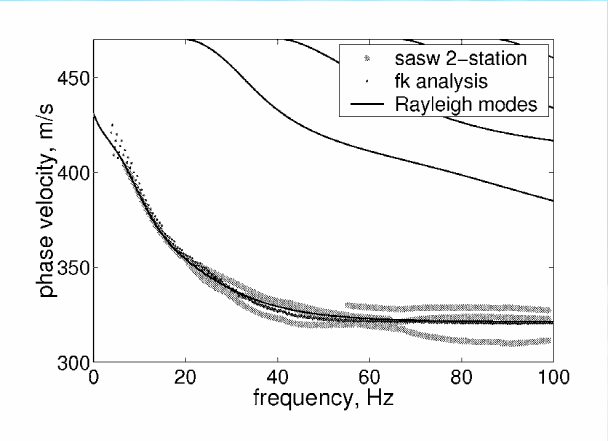
Multistation (fk) vs 2-station SASW

Synthetic datasets

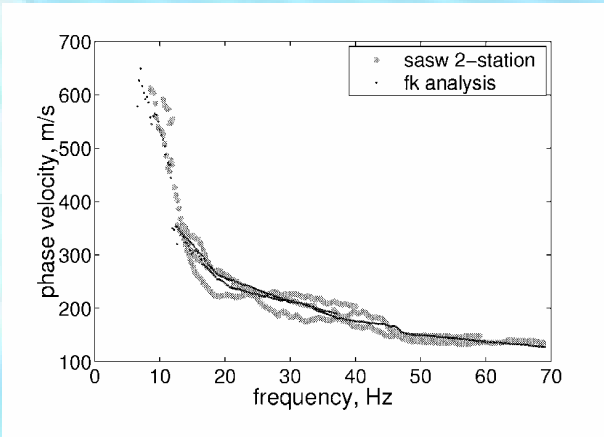
(Foti, 2002)

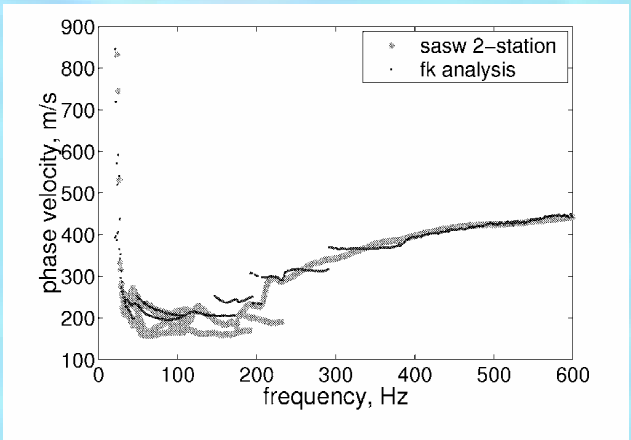


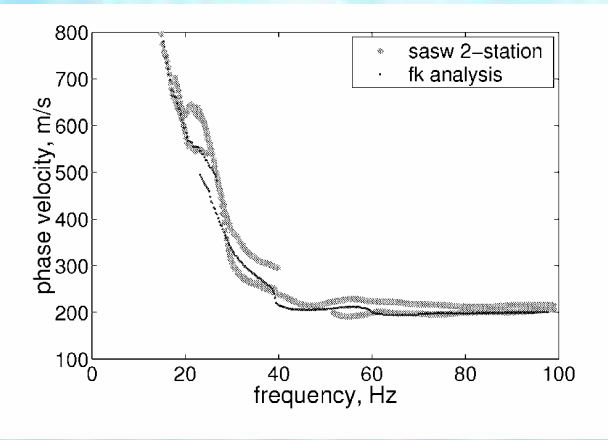




Real experimental data

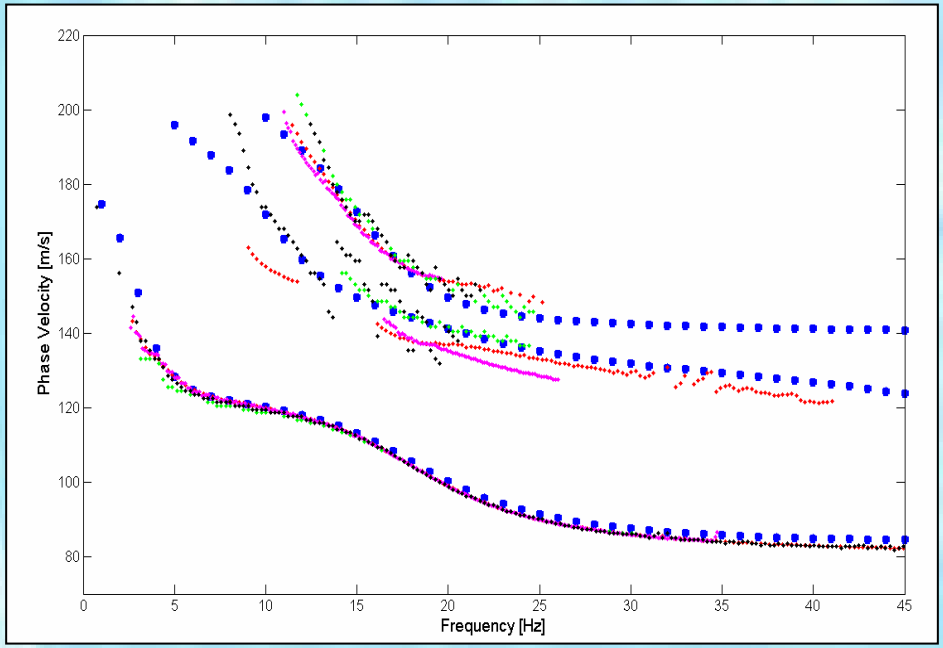






Active test: *fk* vs. *fp*

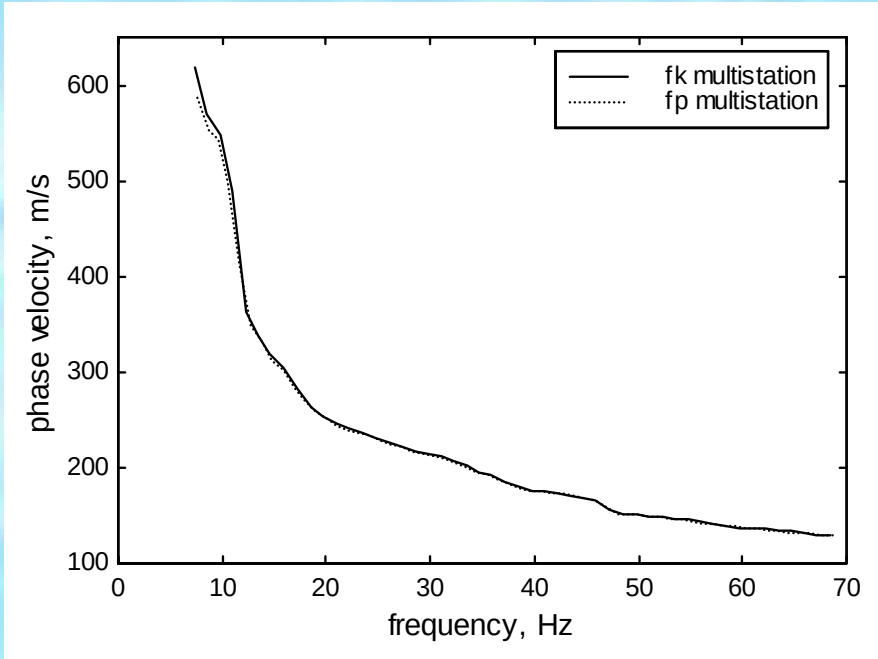
Synthetic data



- Theoretical Modes (Haskell and Thomson)
- FK
- FK Music
- ω-p
- Wavefield - Transformation (Park)

(Boiero & Socco, 2007)

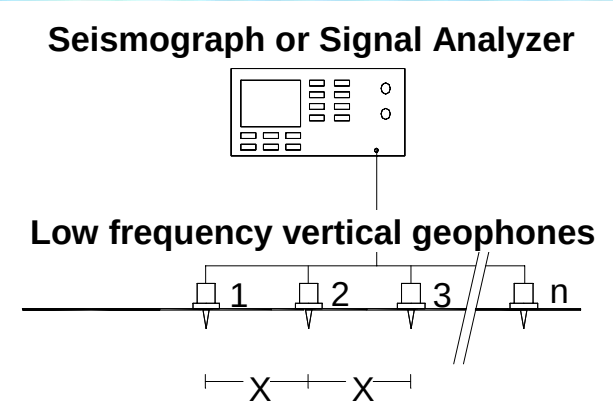
Saluggia test site



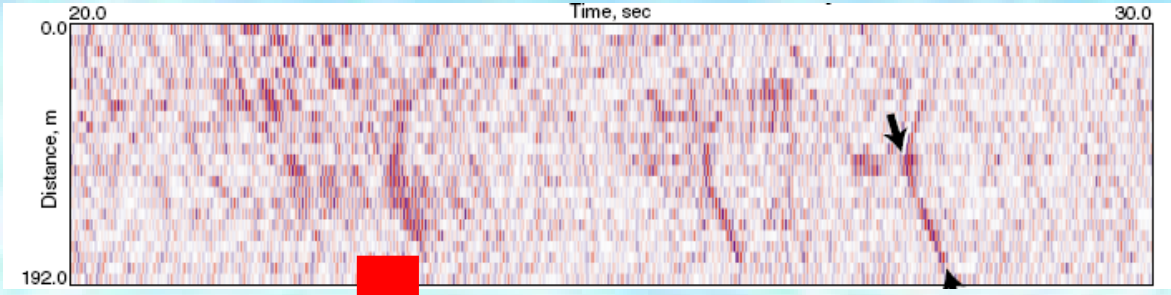
(Foti, 2000)

REMI (Refraction Microtremors)

= Passive Surface Wave Tests with linear arrays



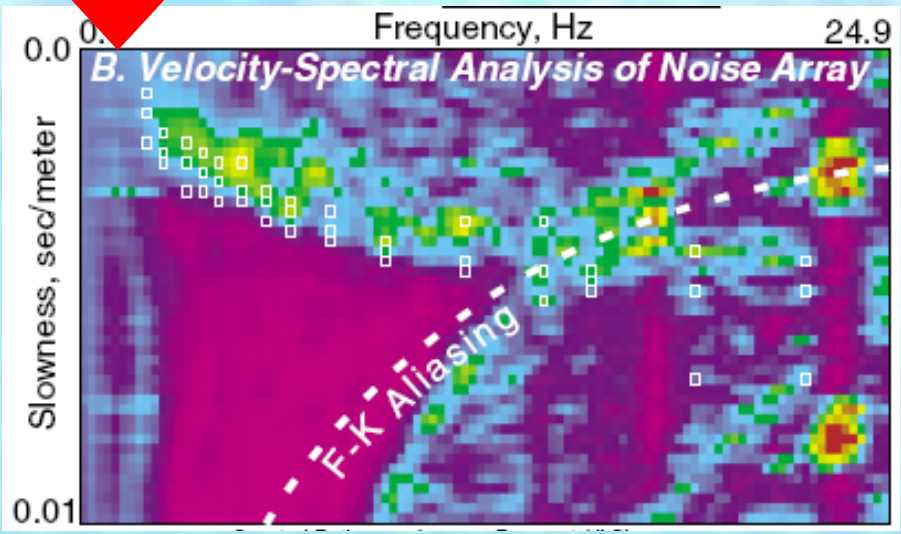
(Louie, 2001)



τ-p transform

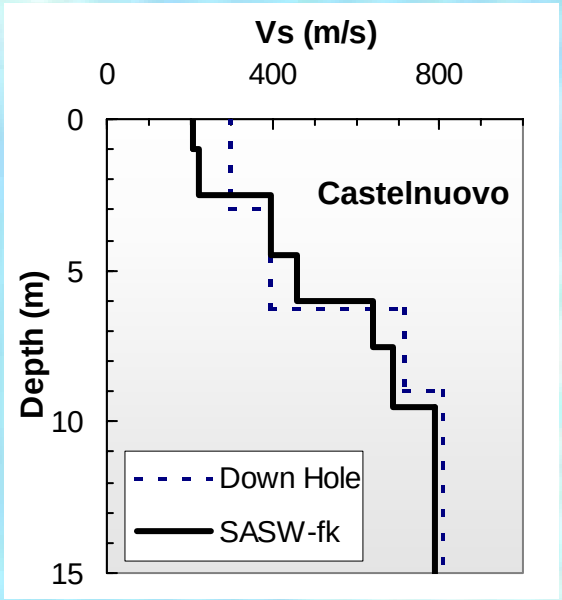
Note: It is assumed a uniform spatial distribution of sources all around the site
→ Localised sources not in line with the array can cause overestimation of VS profile

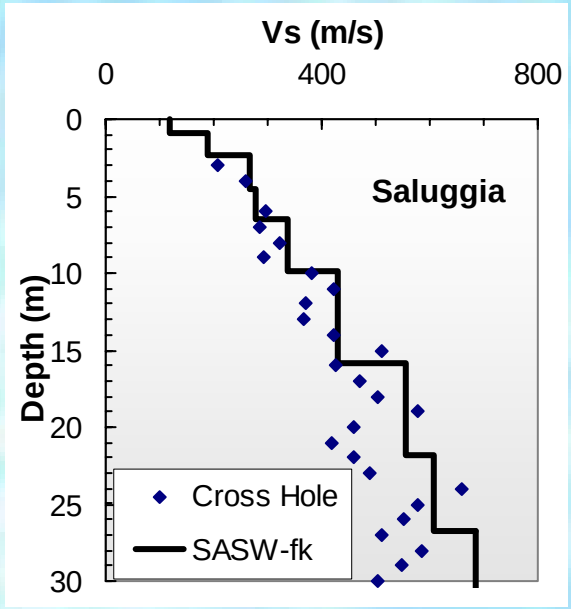
(Louie, 2001)

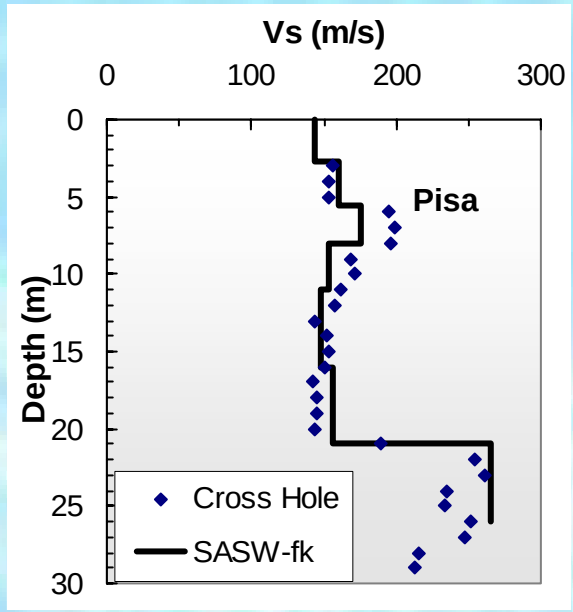


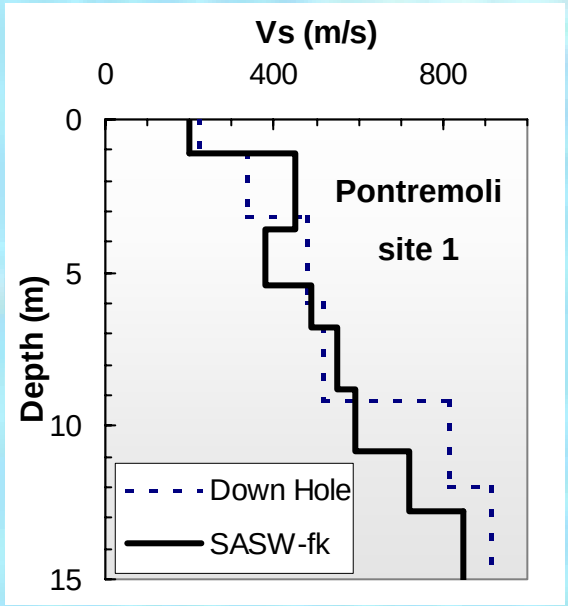
Same configuration of active test:
It is advisable to use active+passive?

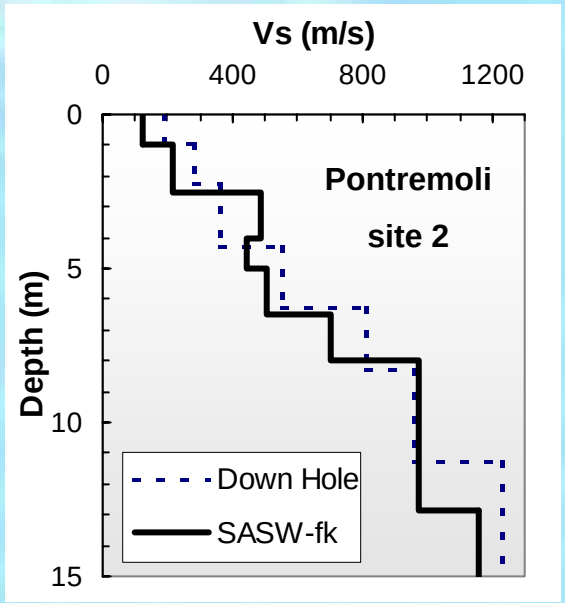
Comparison with Borehole Seismic Methods

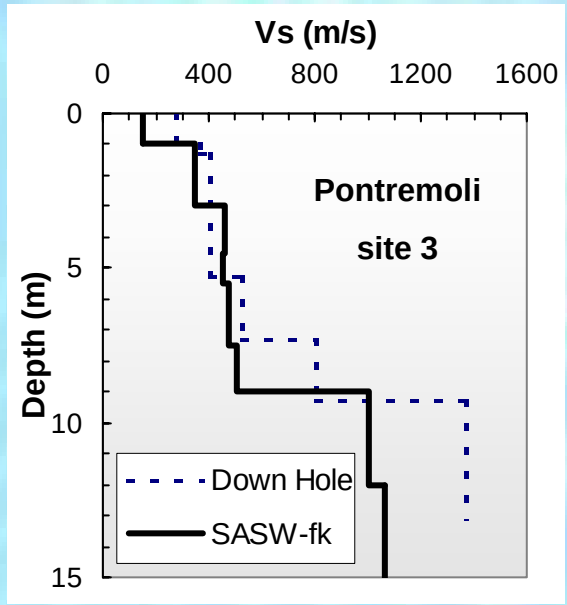






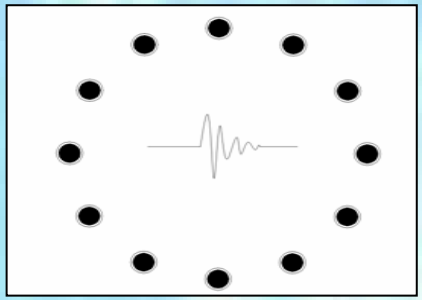




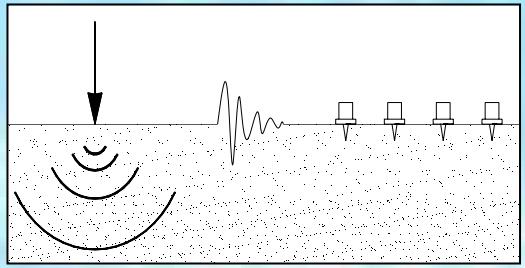


A+P - SW Tests

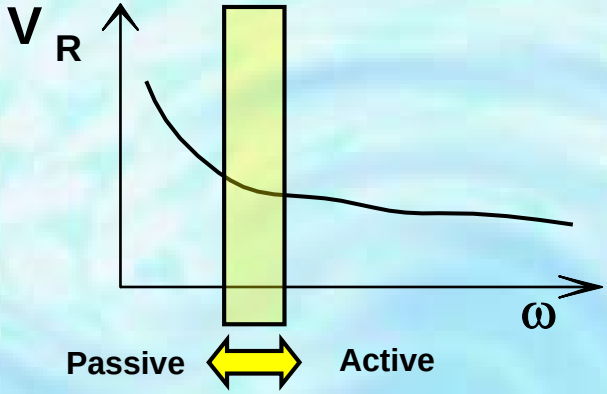
Passive



Active



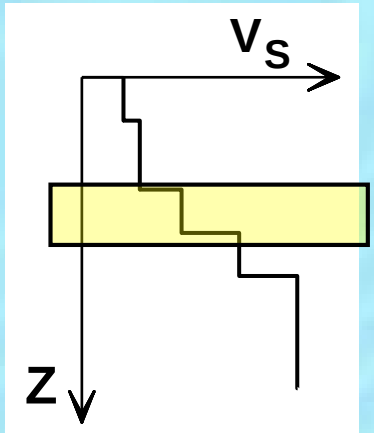
Processing



Inversion

Active

Passive



Passive - SW Tests

Frequency Domain Beamformer

Site E

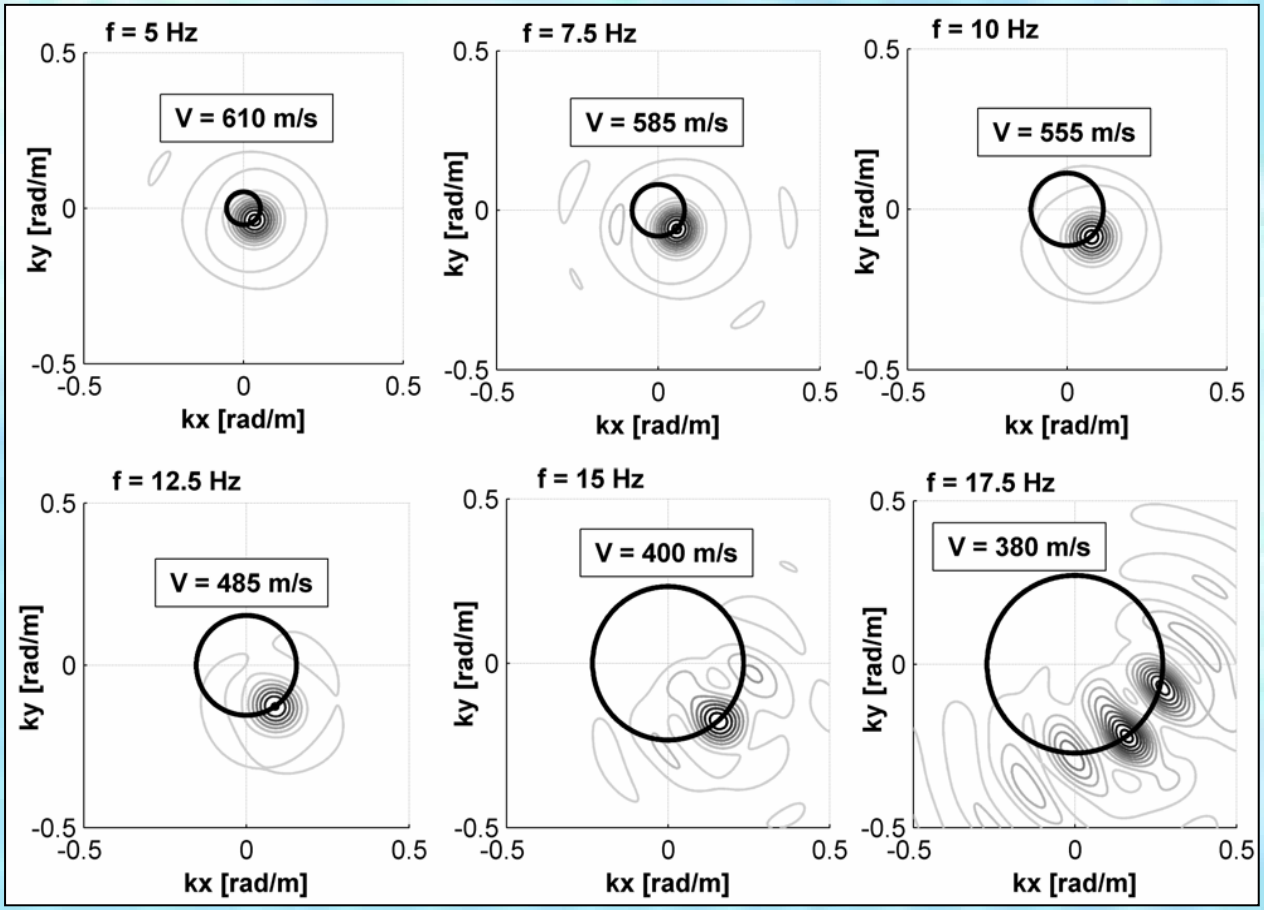
- Peak determination is repeated for each frequency:

$$f = 5\,Hz$$

$$\left|\vec{k}\right| = 0.0515\,rad/m$$

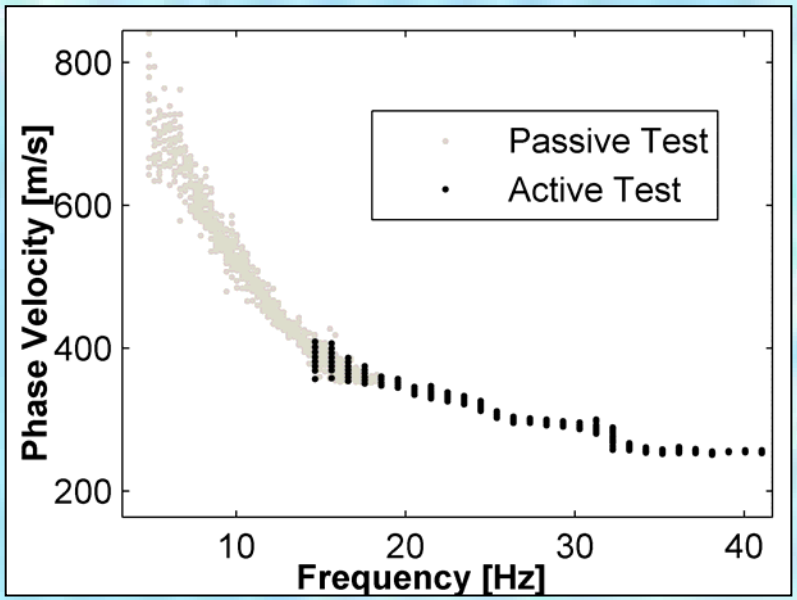
$$V_R = \frac{\omega}{\left|\vec{k}\right|} = \frac{2\pi(24.5\,Hz)}{0.0515\,rad/m}$$

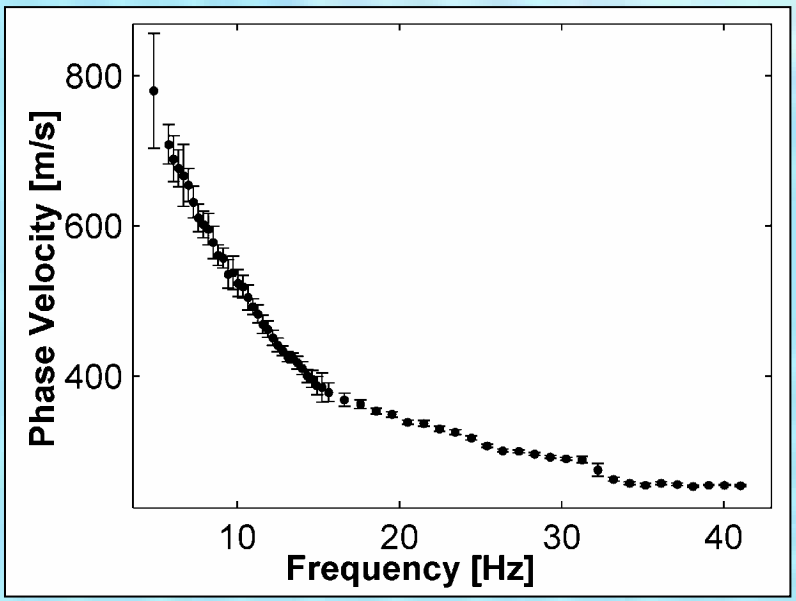
$$= 610\,m/\sec$$



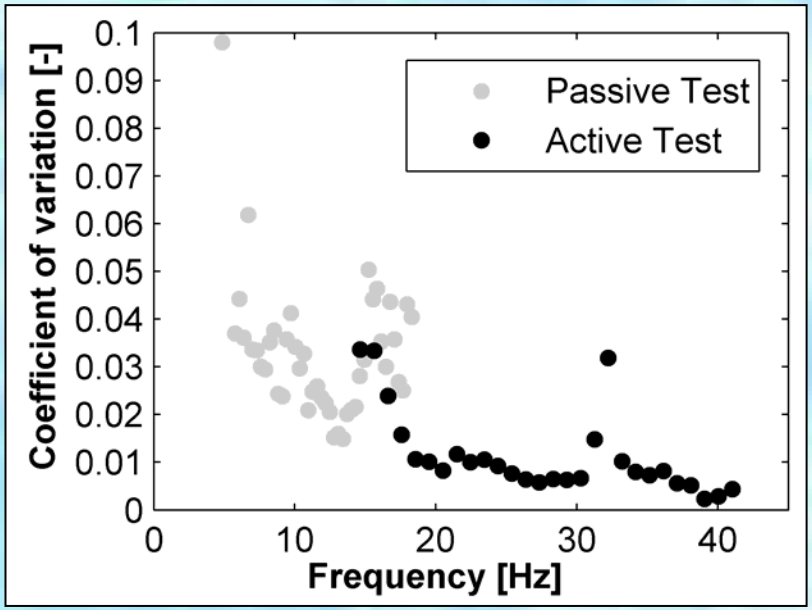
(Foti et al., 2007)

SW Tests – Data Uncertainty





La Salle (Val d'Aosta): Site E



Foti S., Comina C., Boiero D. (2007) "Reliability of combined active and passive surface wave methods", RIG, Vol. 41 (2), 39-47

SW Tests – MC Inversion

Global search inversion method

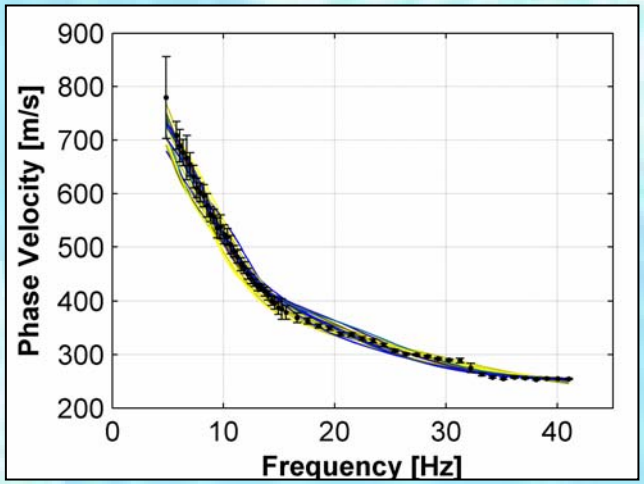
- Randomly generated profiles (V_S vs depth).
- Use of the scaling properties of Rayleigh wave dispersion to optimize the exploration of Model Parameter Space.
- A statistical test is used to select equivalent profiles accounting for data uncertainties.

SW Tests - Uncertainty

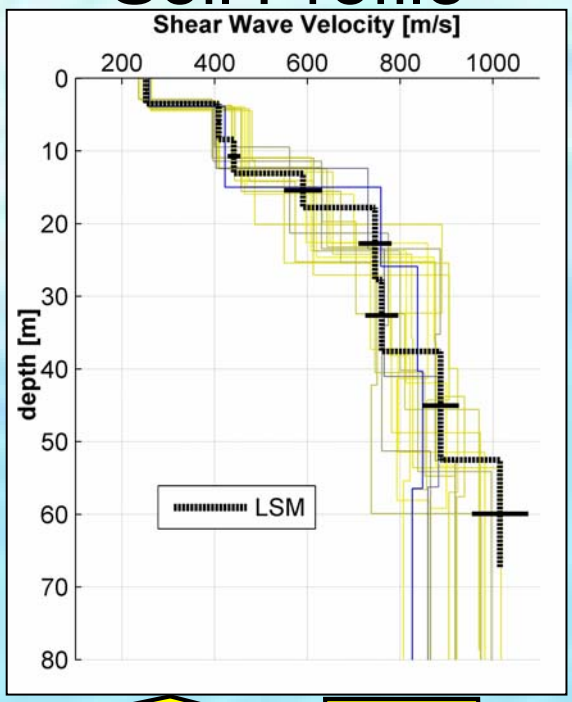
Using Montecarlo inversion it is possible to study the uncertainty (equivalence) and its consequences

Active + Passive surface waves data

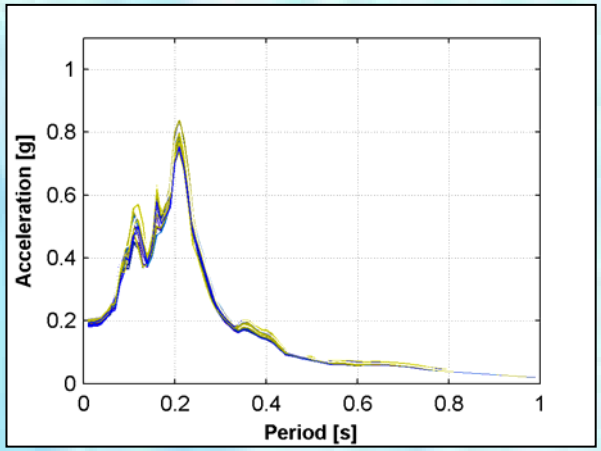
Data



Soil Profile



Local Site Response



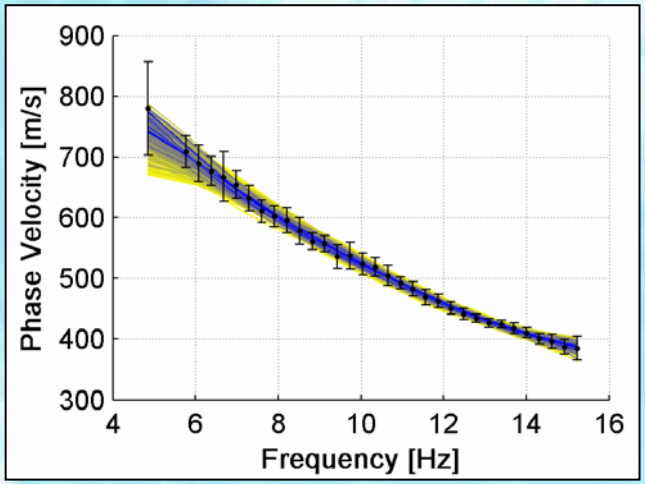
Foti S., Comina C., Boiero D., Socco L.V. (2008) “Non uniqueness in surface wave inversion and consequences on seismic site response analyses”, submitted to Soil Dyn. and Earthq. Eng.

SW Tests - Uncertainty

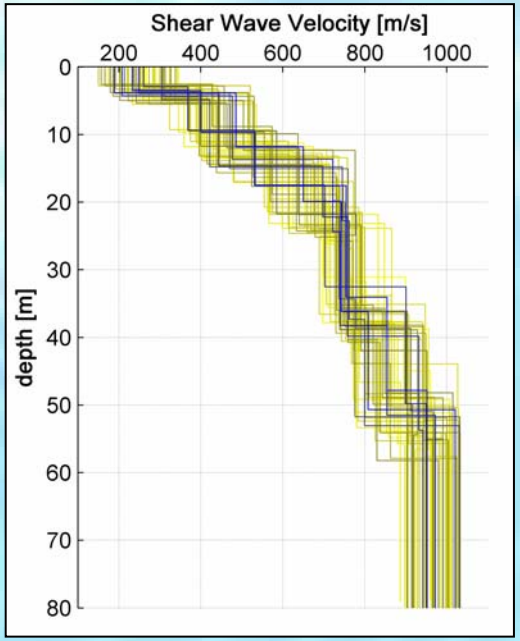
Using Montecarlo inversion it is possible to study the uncertainty (equivalence) and its consequences

Passive surface waves data

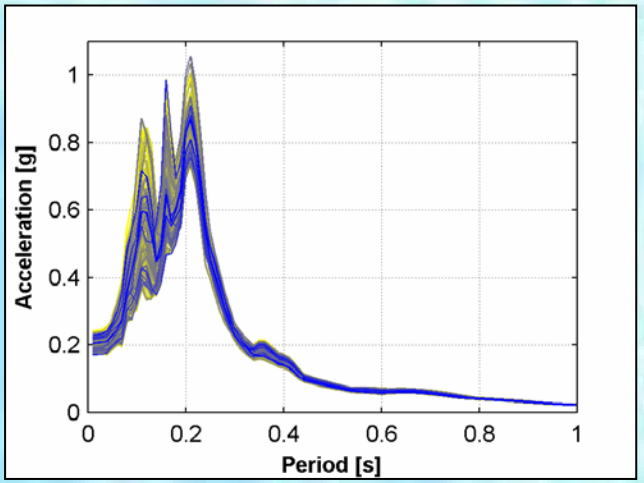
Data



Soil Profile



Local Site Response

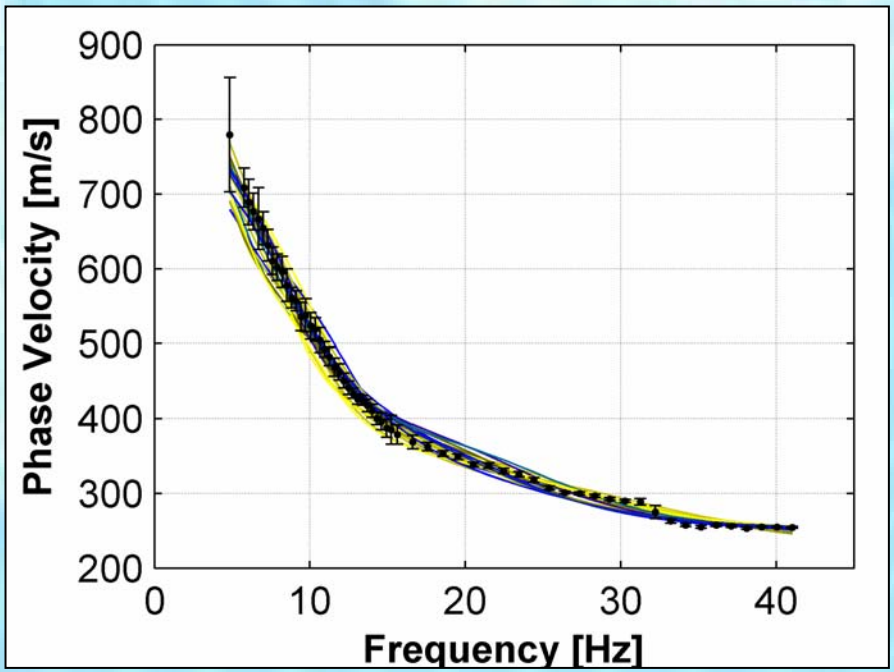


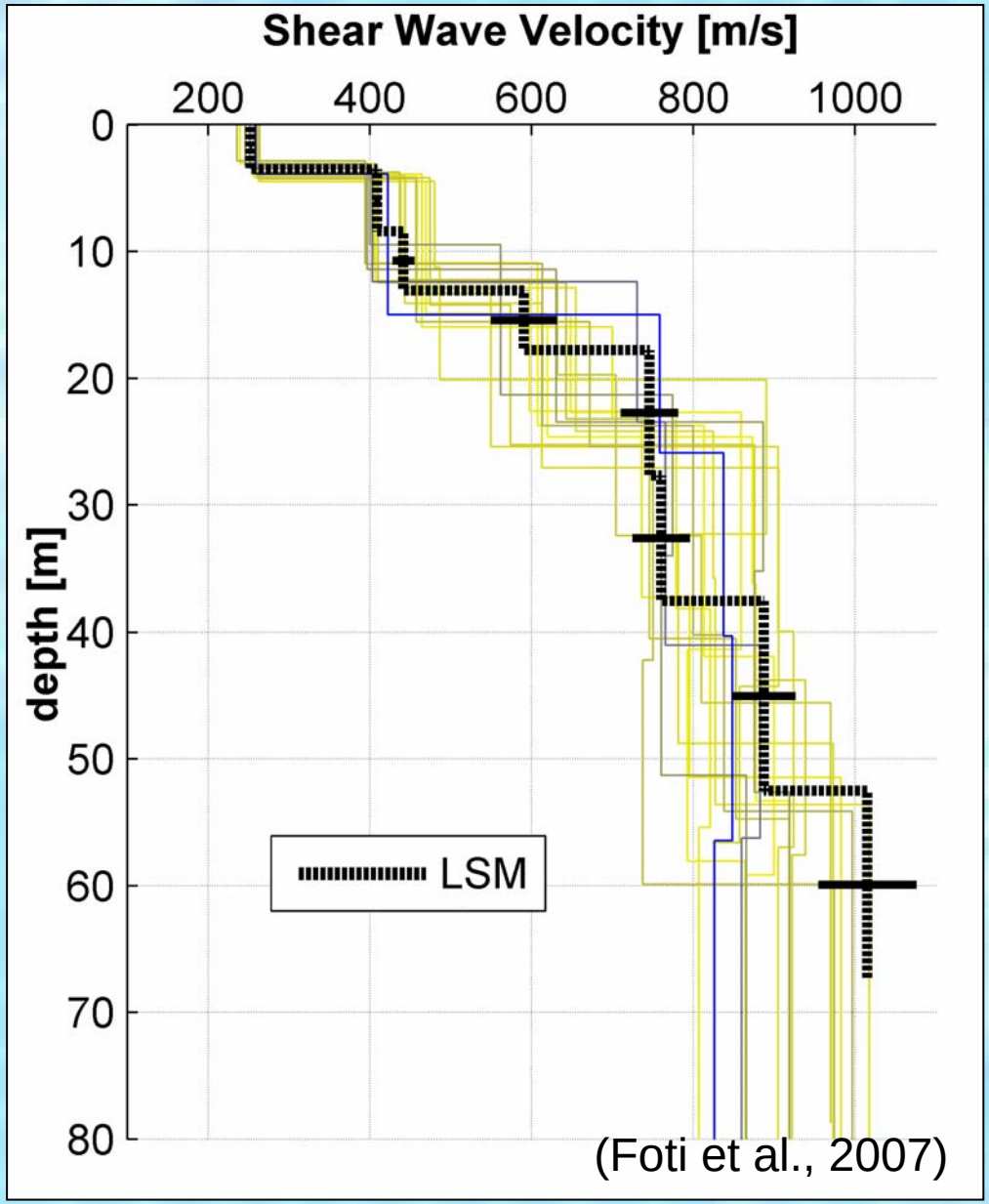
Foti S., Comina C., Boiero D., Socco L.V. (2008) “Non uniqueness in surface wave inversion and consequences on seismic site response analyses”, submitted to Soil Dyn. and Earthq. Eng.

SW Tests - Uncertainty

Non-uniqueness of the solution

Equivalent Profiles from Monte Carlo Inversion A + P data



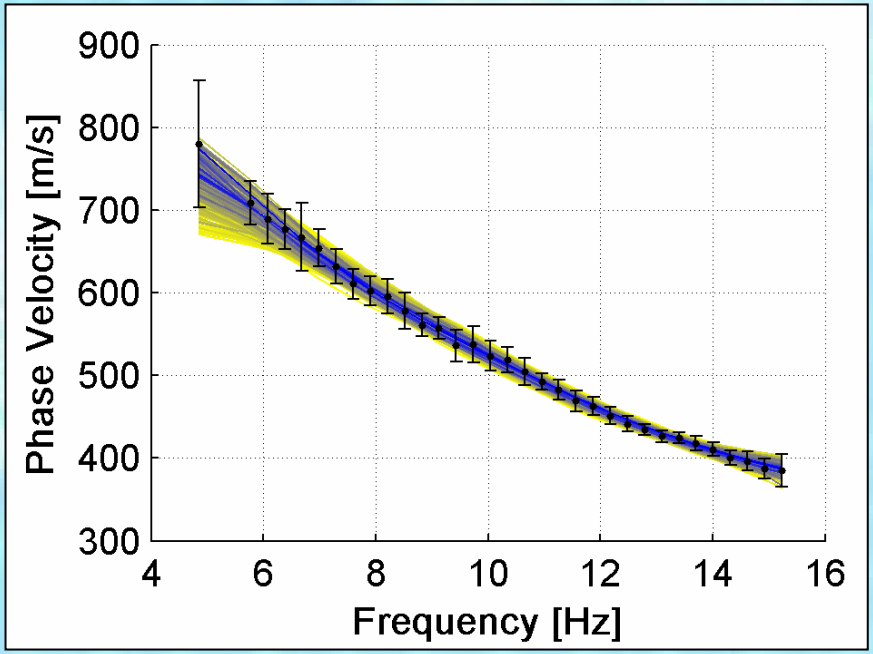


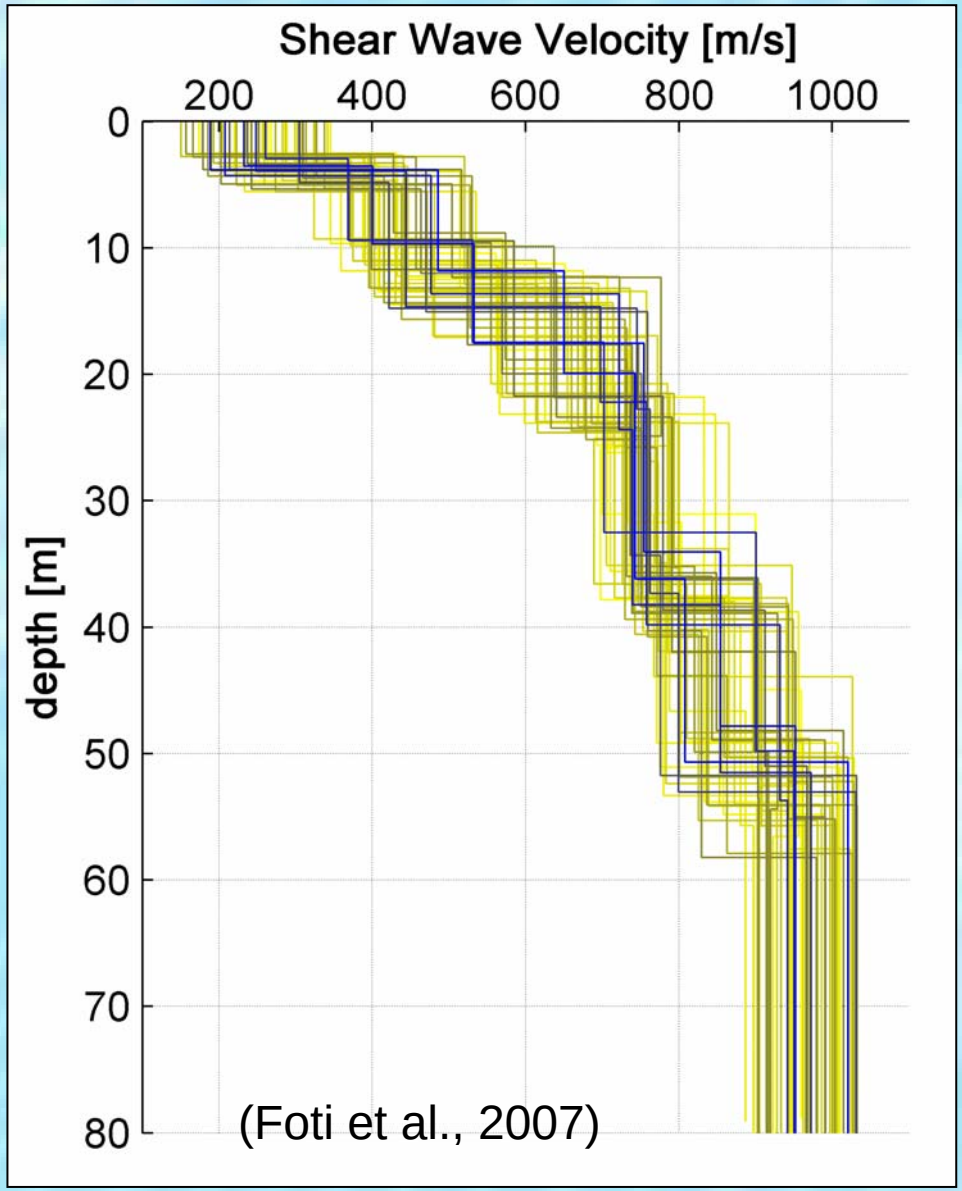
(Foti et al., 2007)

SW Tests - Uncertainty

Non-uniqueness of the solution

Equivalent Profiles
from the
only passive data

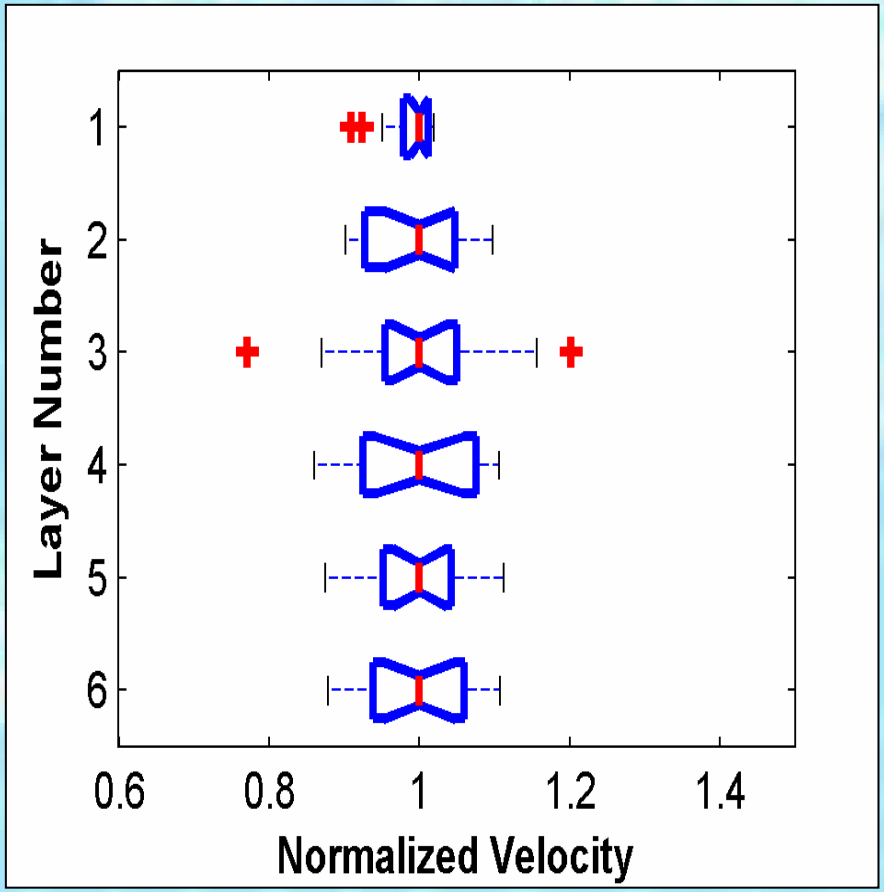




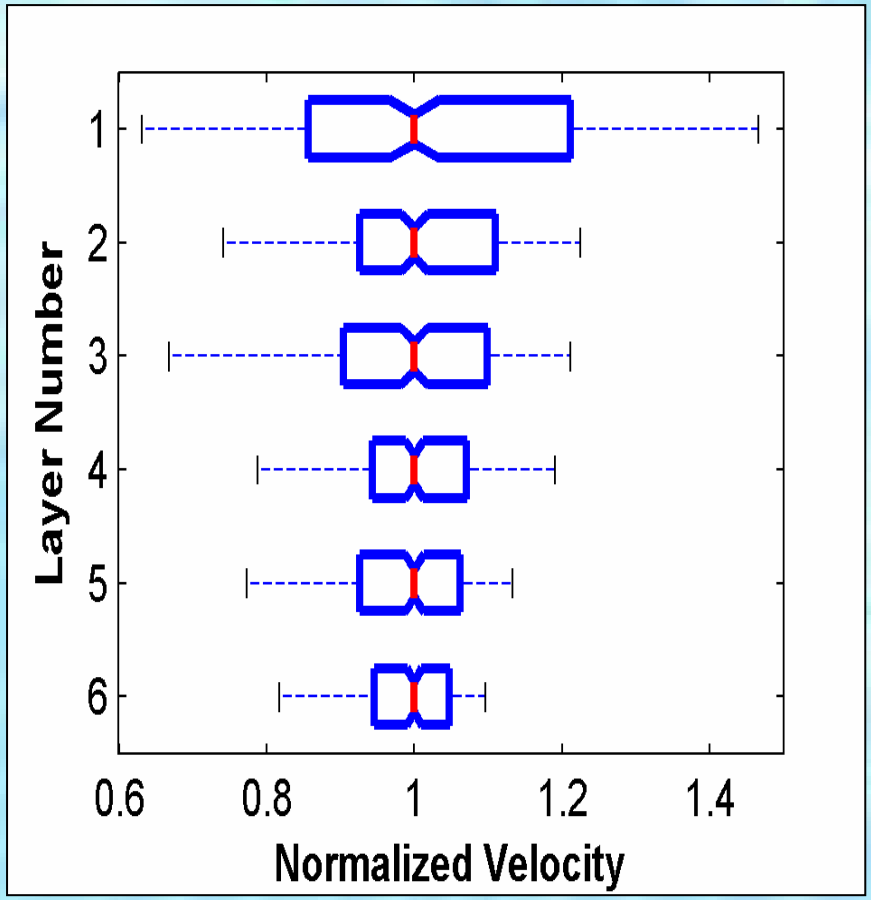
SW Tests - Uncertainty

Uncertainty on the layer velocity

A + P data



Passive data

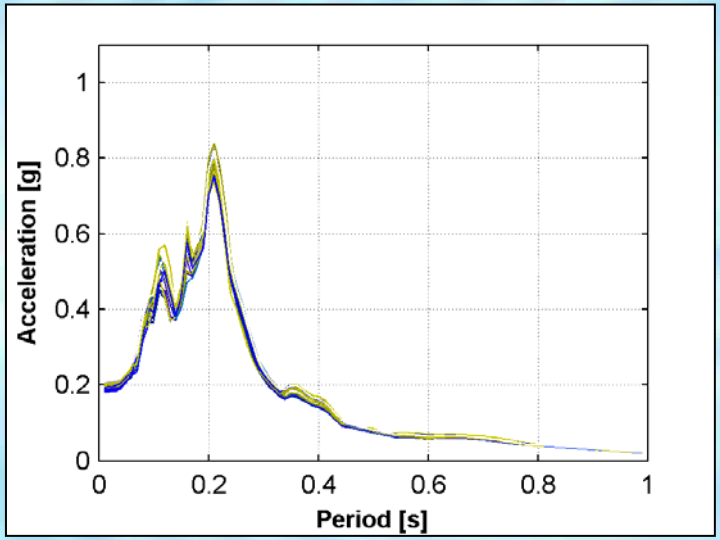


(Foti et al., 2008)

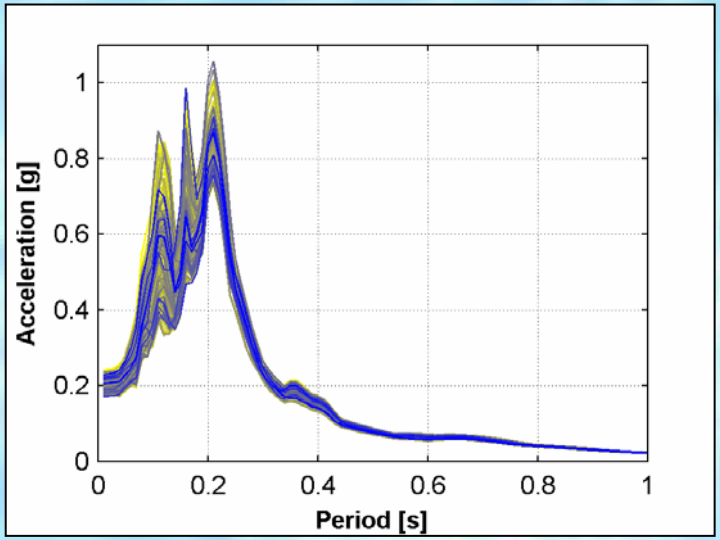
LSR - Uncertainty

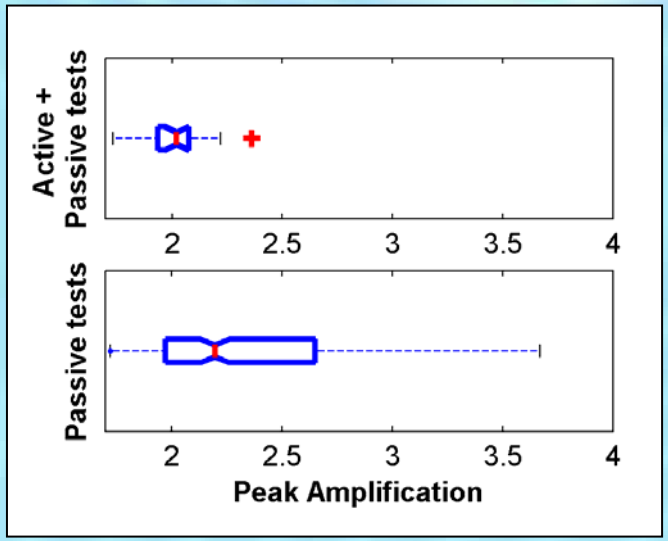
Site E

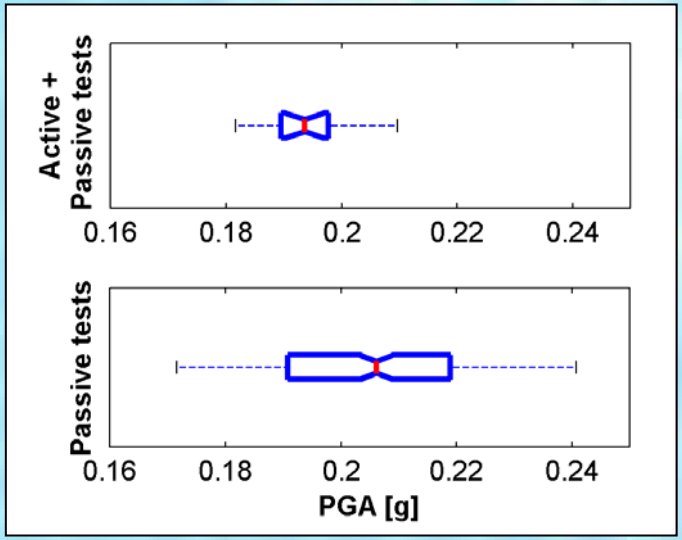
A + P data



Passive data





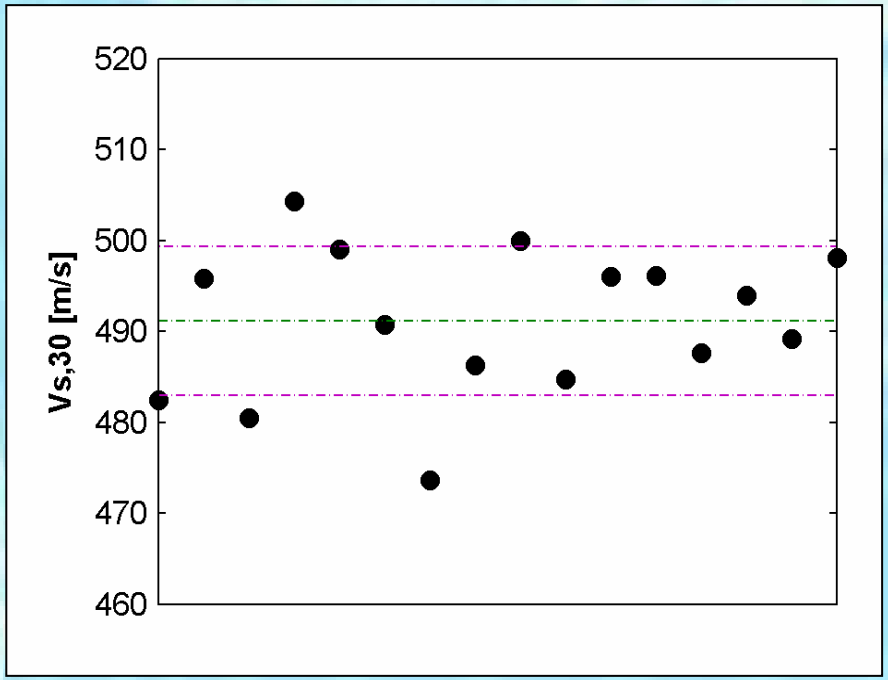


(Foti et al., 2008)

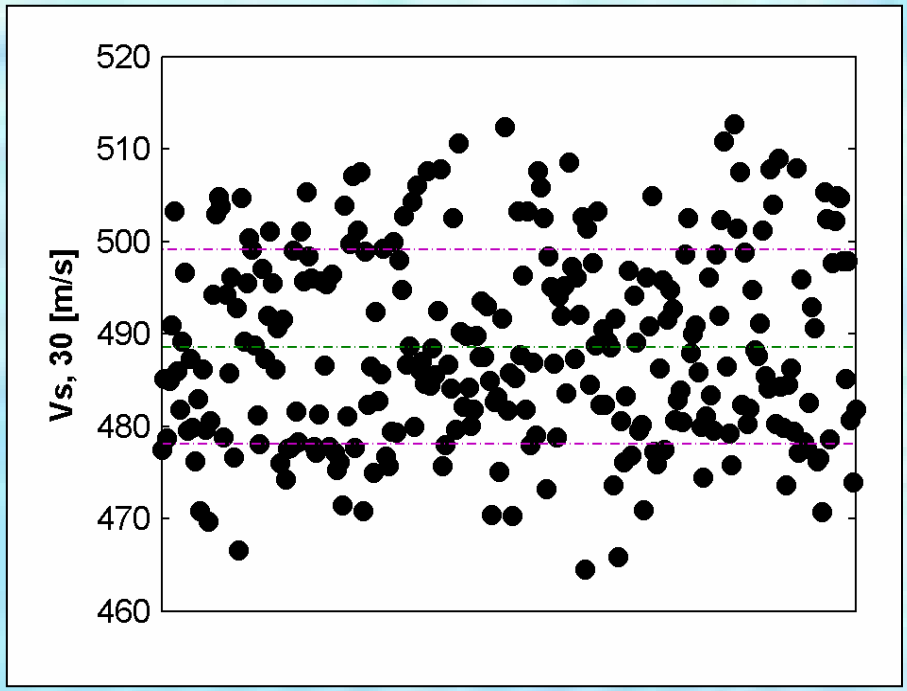
$V_{S,30}$ - Uncertainty

La Salle, Site E

A + P data



Passive data



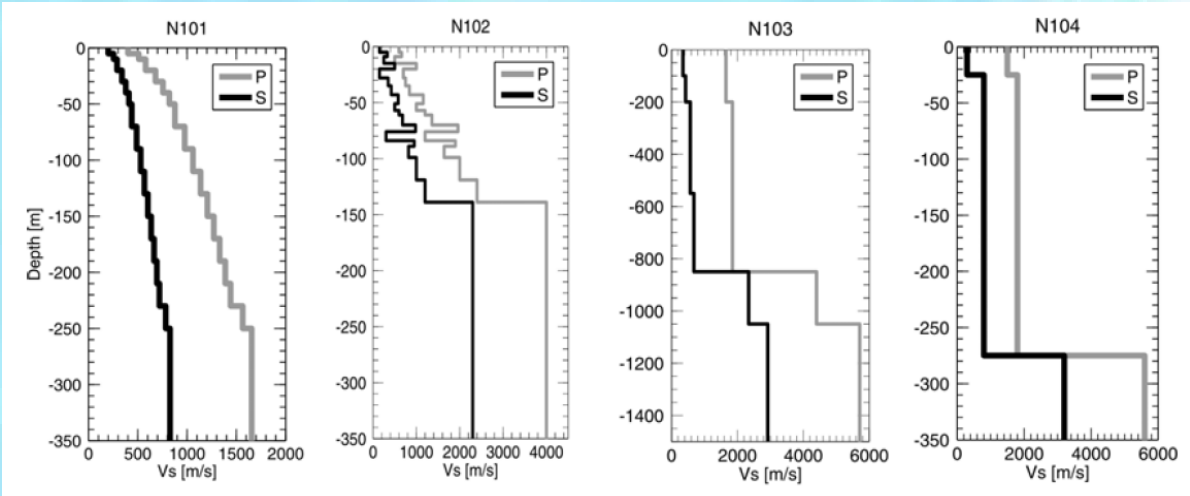
Foti S., Boiero D., Comina C., Socco L.V. (2008) “Consequences of solution non-uniqueness in surface wave tests for seismic response studies”, Proceeding of Geotechnical Earthquake Engineering and Soil Dynamics IV, Sacramento (USA), GSP, ASCE

Remarks

- Consistency of active and passive data
- Relevance of the frequency band of available information
- Consequences of equivalence
- $V_{S,30}$ estimate is robust

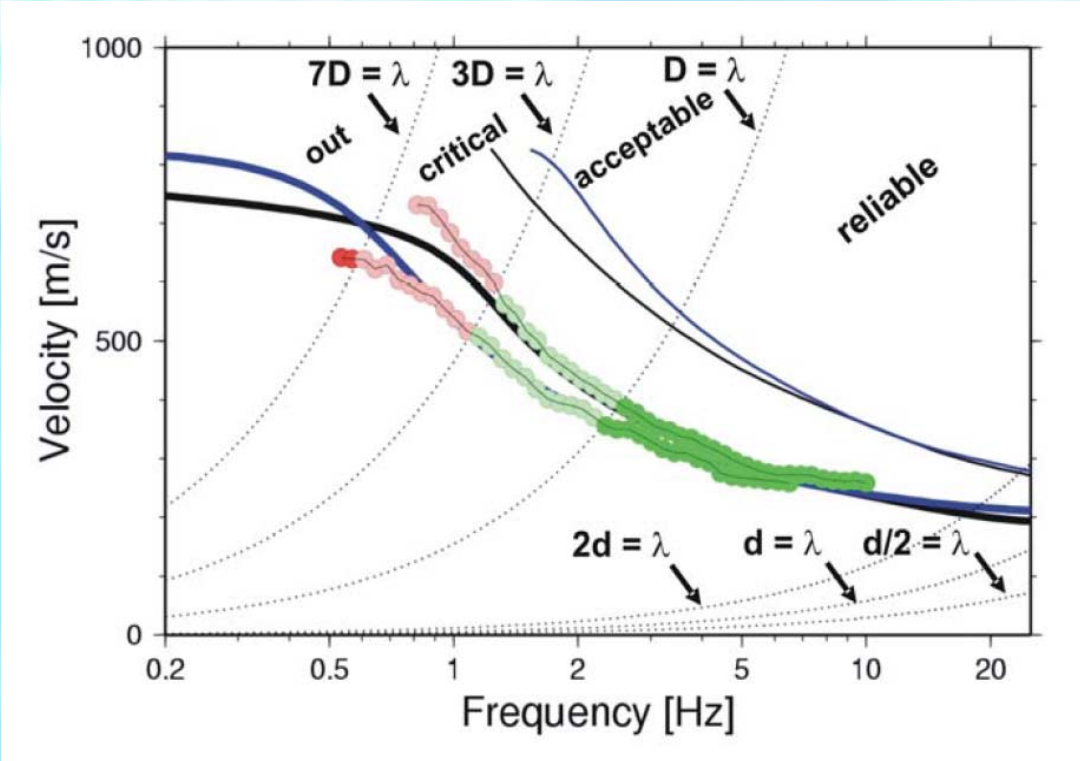
Blind test EGS 2006 (Cornou et al., 2006)

- 4 synthetic and 4 real dataset
- 19 participants
- For synthetics mix of randomly distributed (more favorable for SPAC) and spatially localized sources (may favor FK-based techniques).
- Maybe “too blind”
- Some unrealistic targets for SW testing



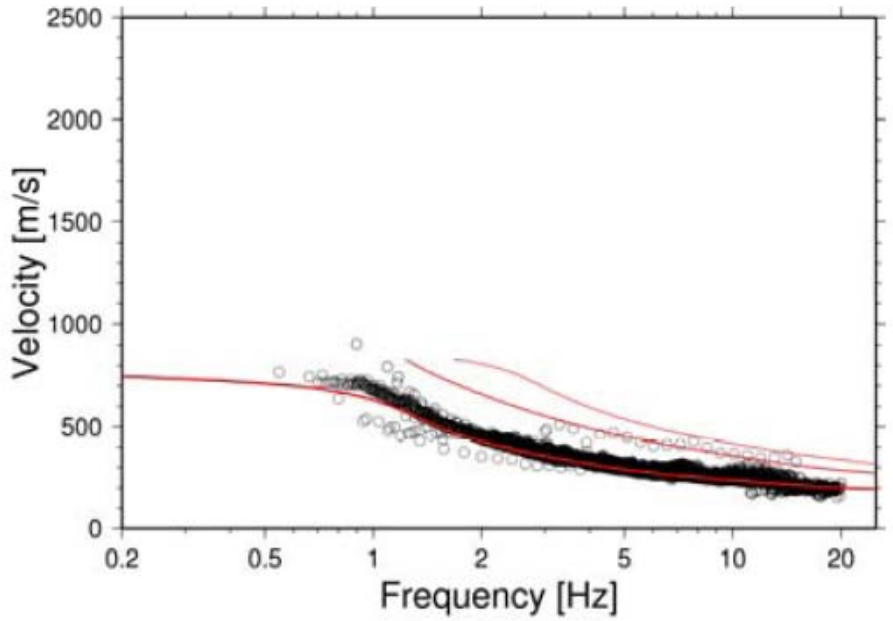
Reliable frequency range

"In most cases, the groups chose to interpret analysis results in a larger frequency band than what is recommended in literature".

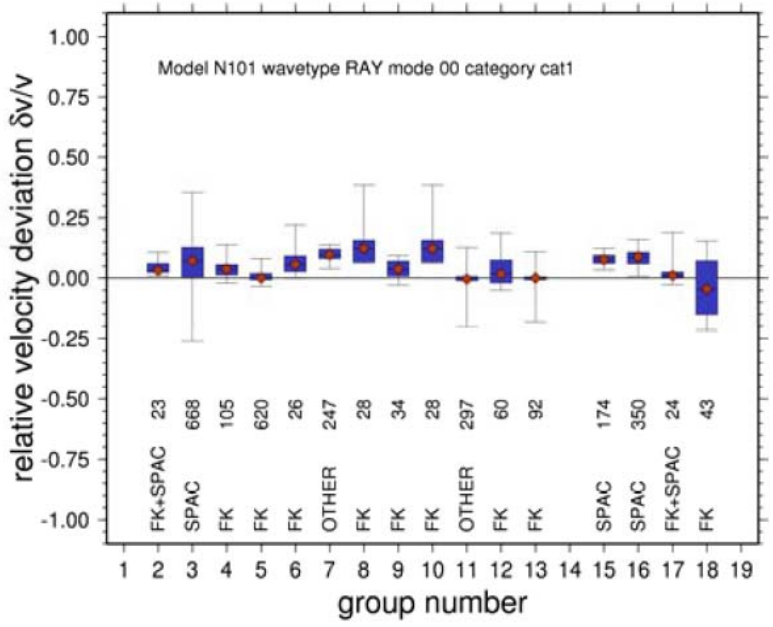


Array dimension is a critical aspect

Synthetic N101



a) N101 – Rayleigh – proportional to velocity

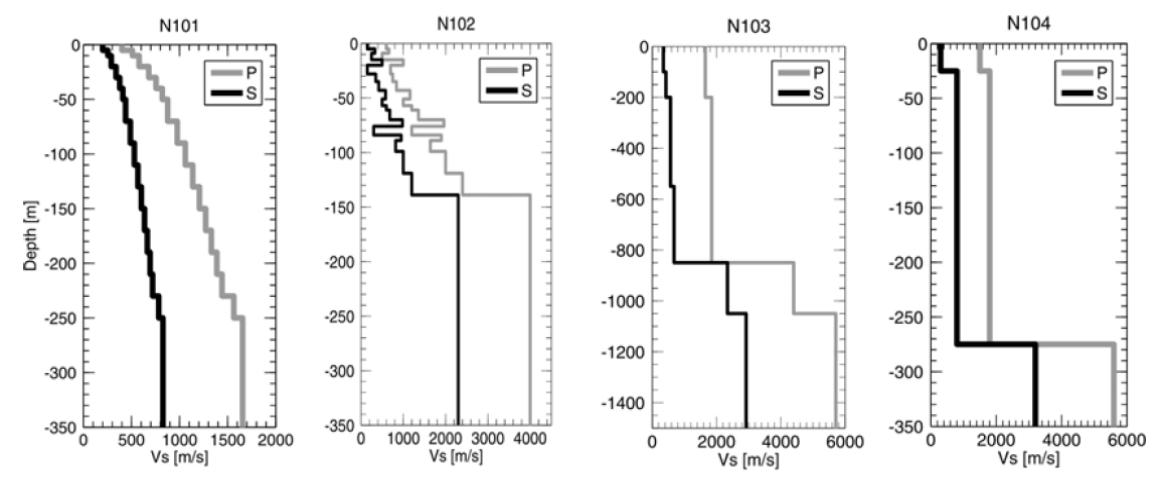


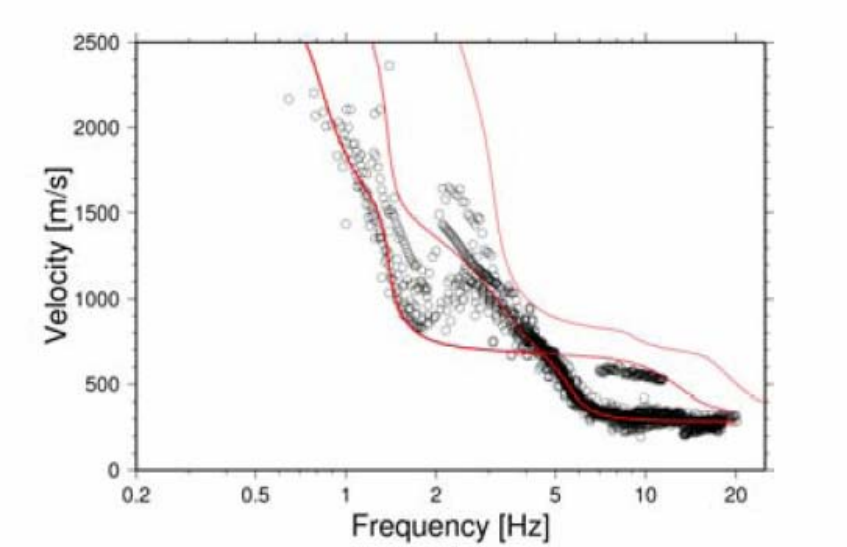
a) N101 – relative velocity deviation – reliable band only

(Cournou, 2006)

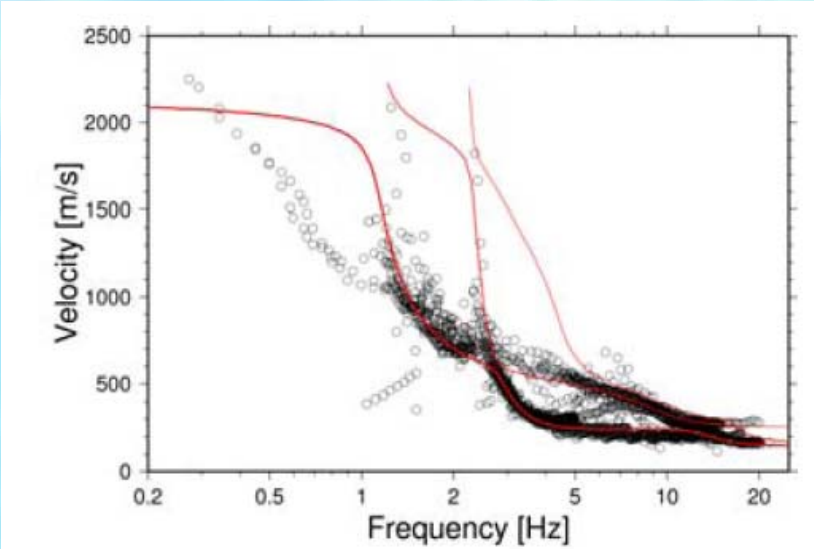
SPAC vs FK
No clear advantage

Relevance of higher modes and correct mode identification



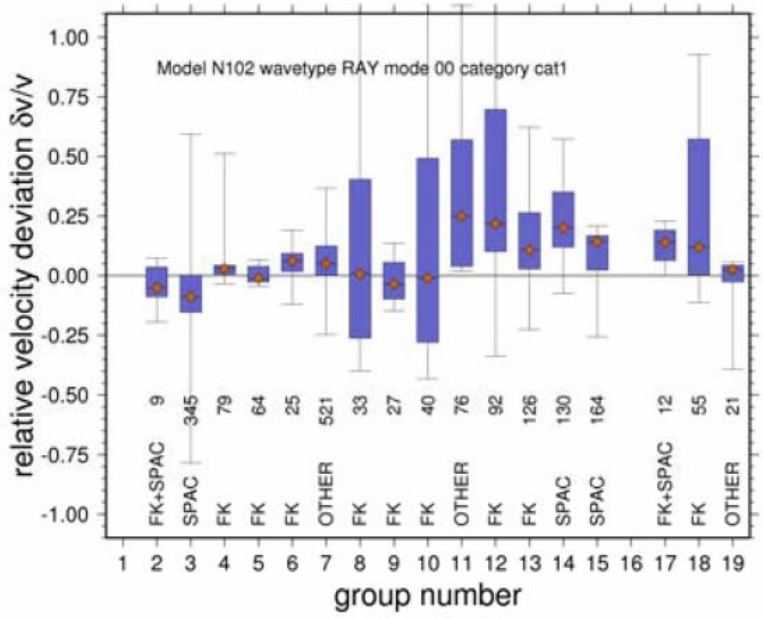


N104 – Rayleigh – velocity proportional

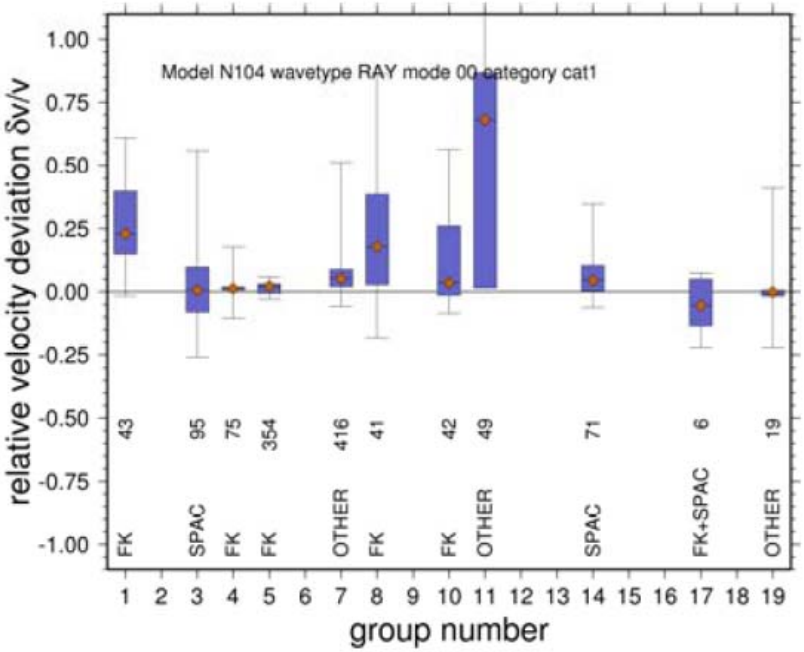


N102 – Rayleigh – velocity proportional

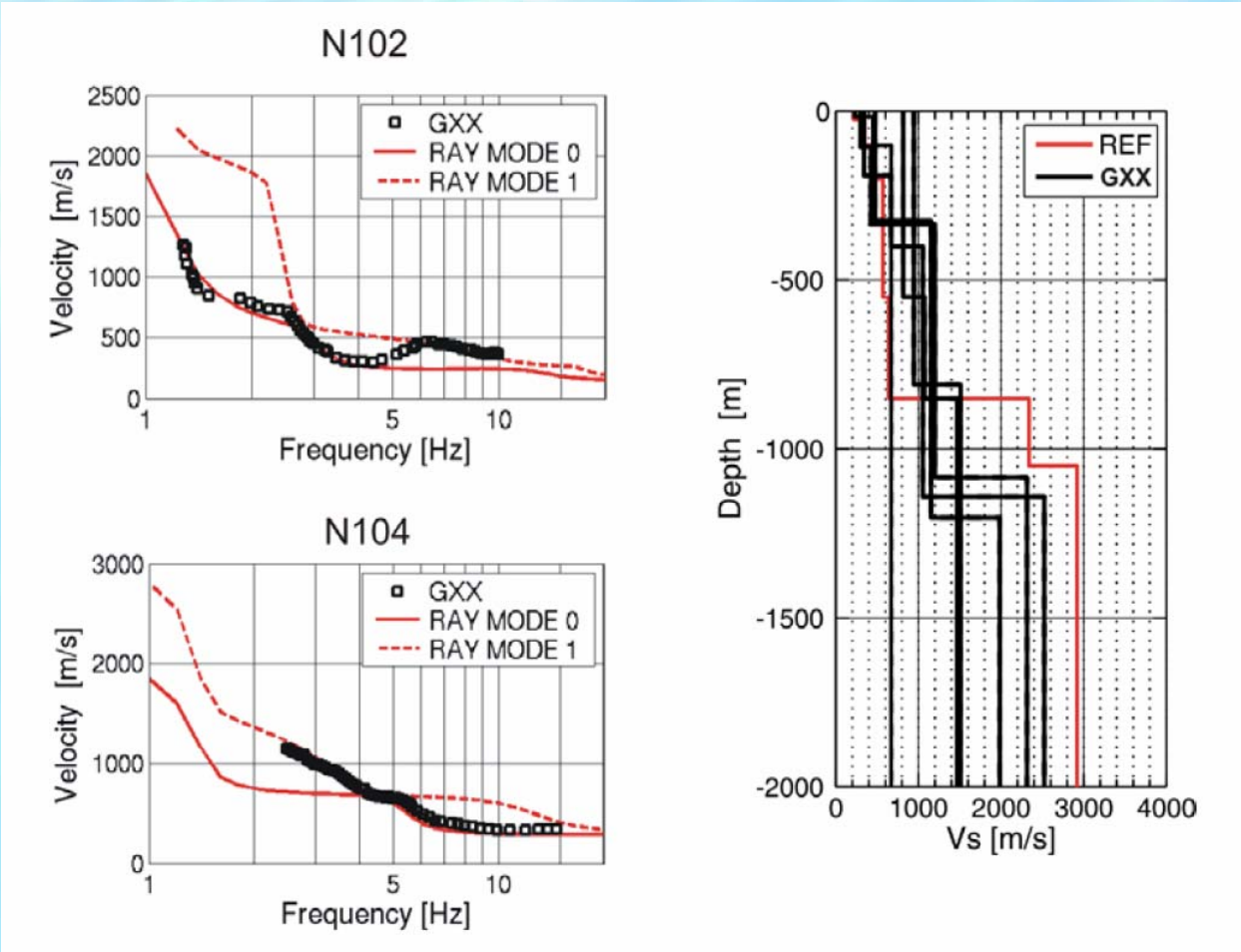
(Cournou, 2006)



a) N102 – relative velocity deviation – reliable band only.

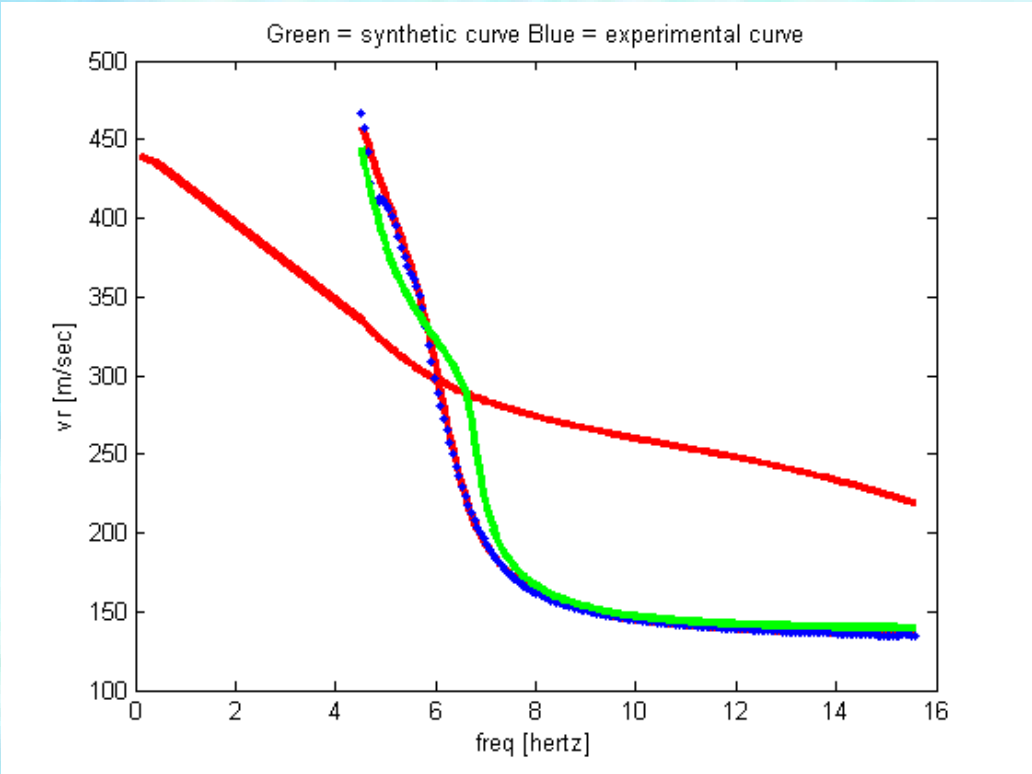


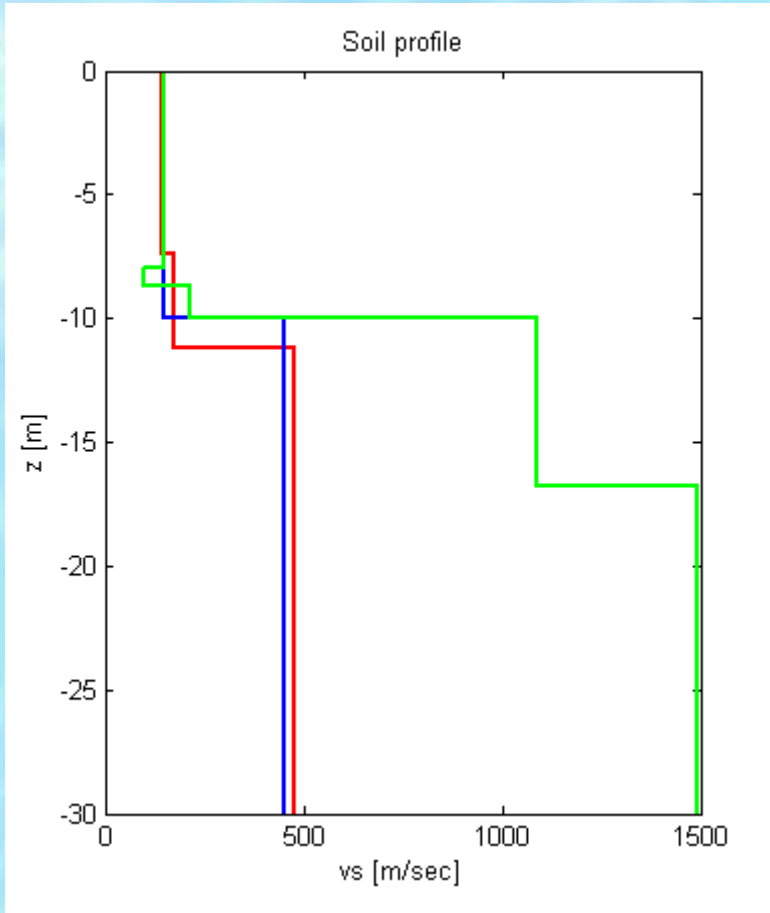
a) N104 – relative velocity deviation – reliable band only.


N102
Velocity [m/s]
Frequency [Hz]
GXX
RAY MODE 0
RAY MODE 1
N104
Velocity [m/s]
Frequency [Hz]
GXX
RAY MODE 0
RAY MODE 1
Depth [m]
Vs [m/s]
REF
GXX

Relevance of higher modes

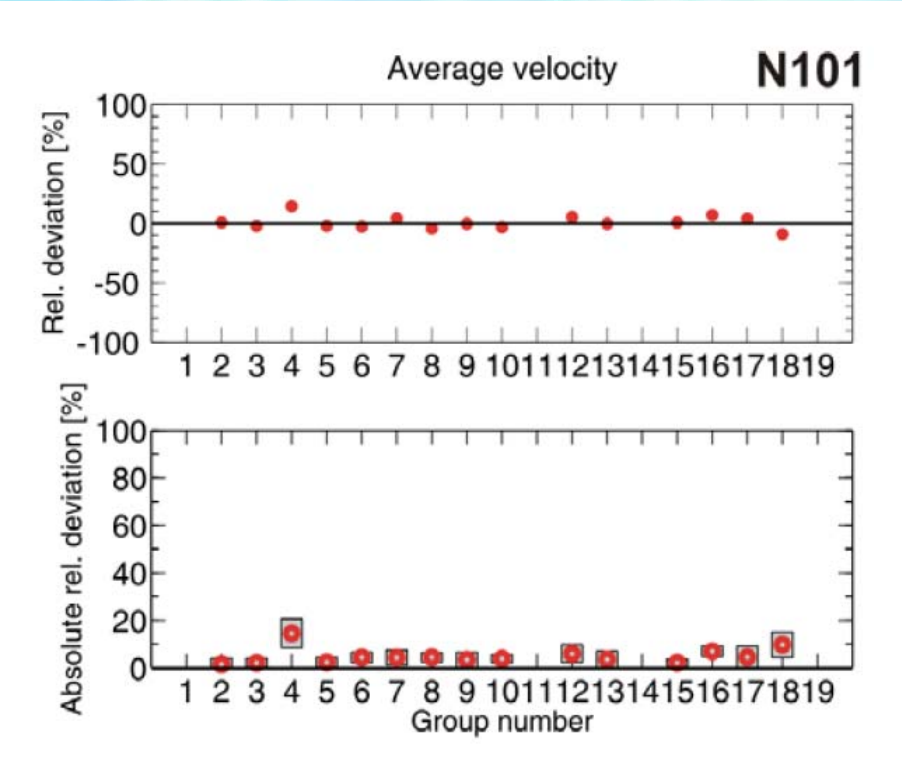
Inversion with an innovative method based on L_1 norm of the Haskell-Thomson matrix determinant (it doesn't require the identification of mode number)

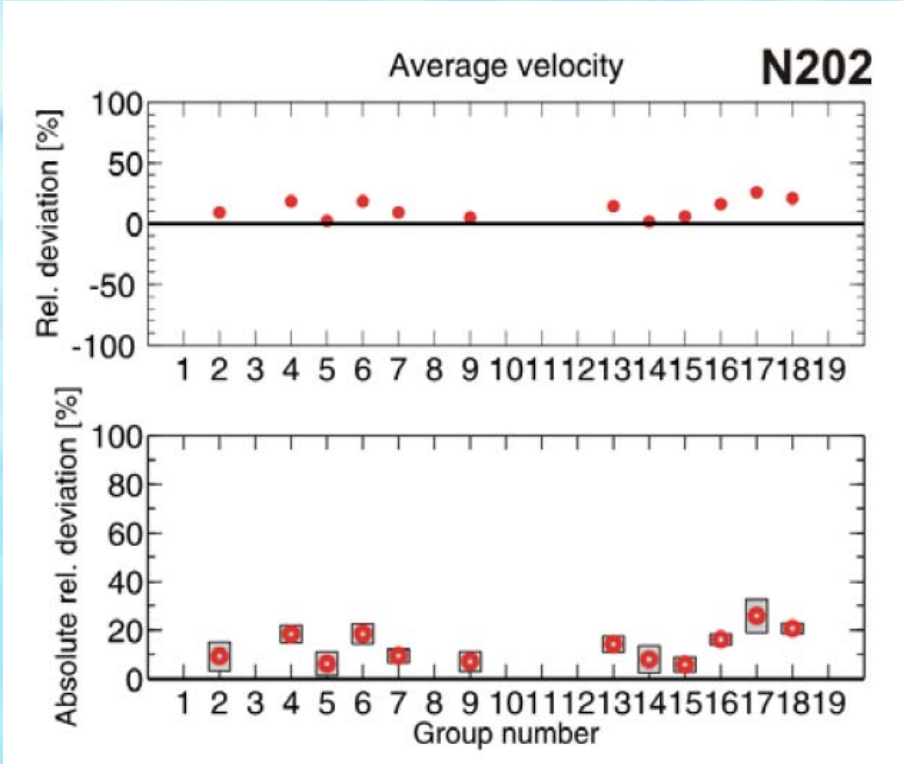




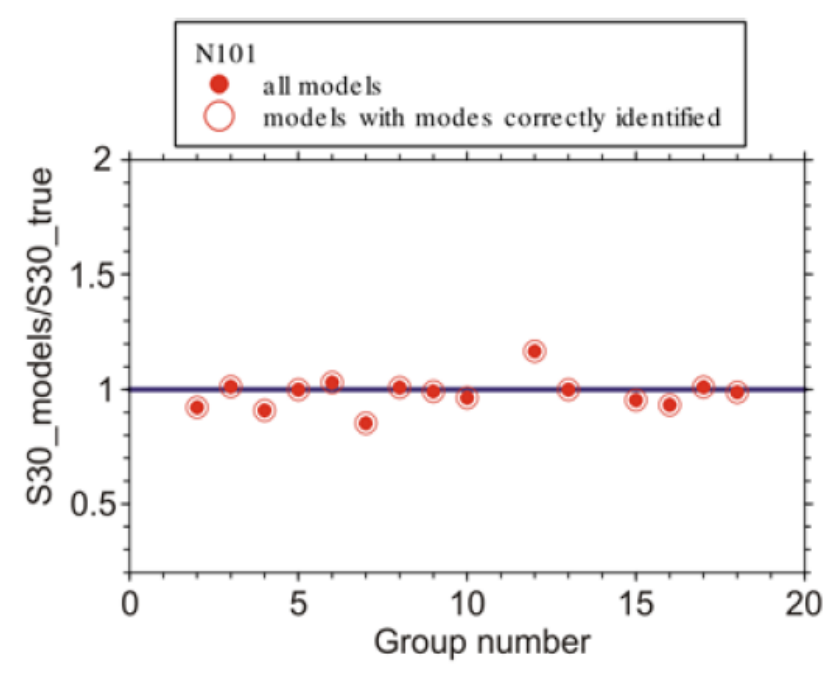
Maraschini M., Ernst F., Boiero D., Foti S., Socco V. (2008) "Innovative multimodal inversion of surface wave data", 70th EAGE Conf., Rome, 9-12 June 2008, CD-Rom

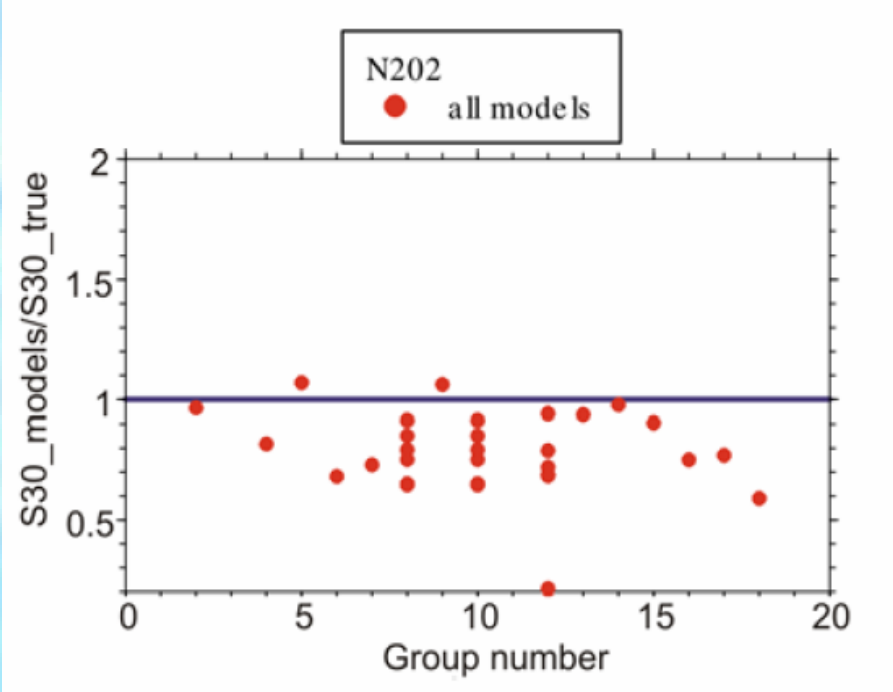
Average velocities





(Cournou, 2006)

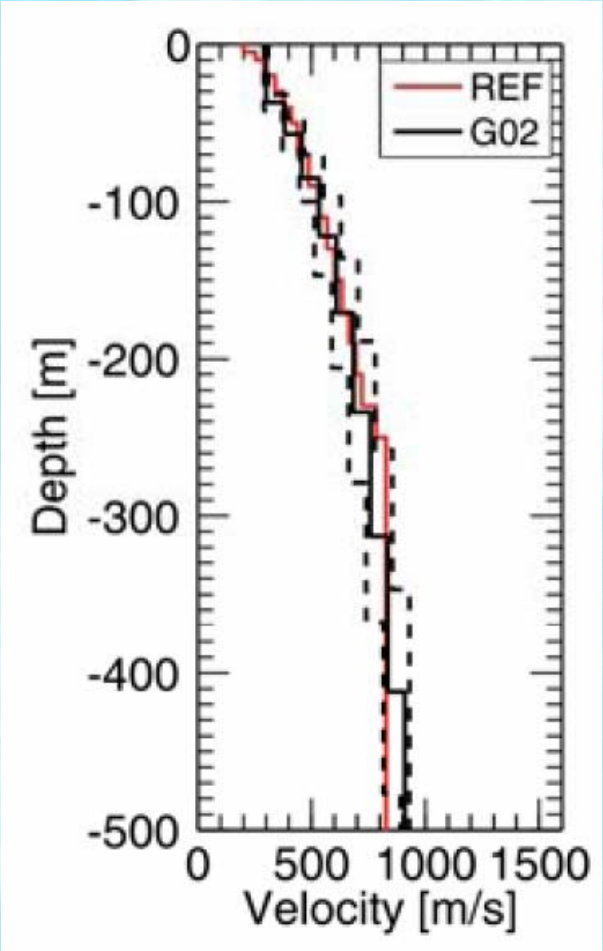


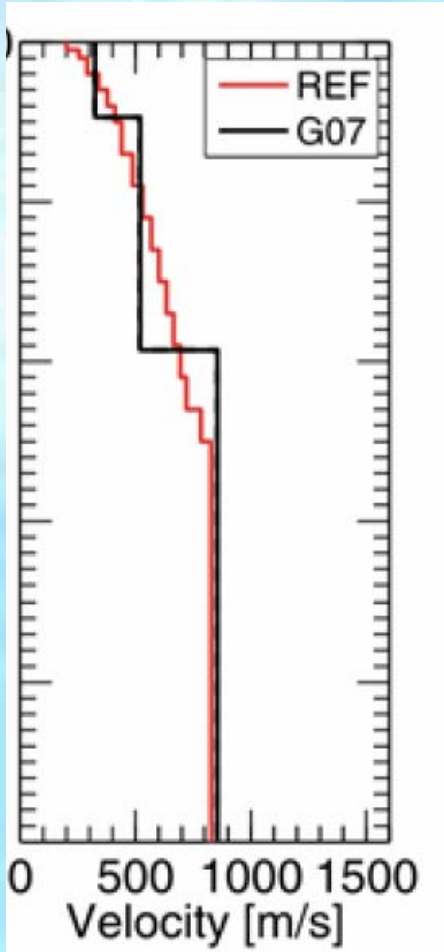


(Cournou, 2006)

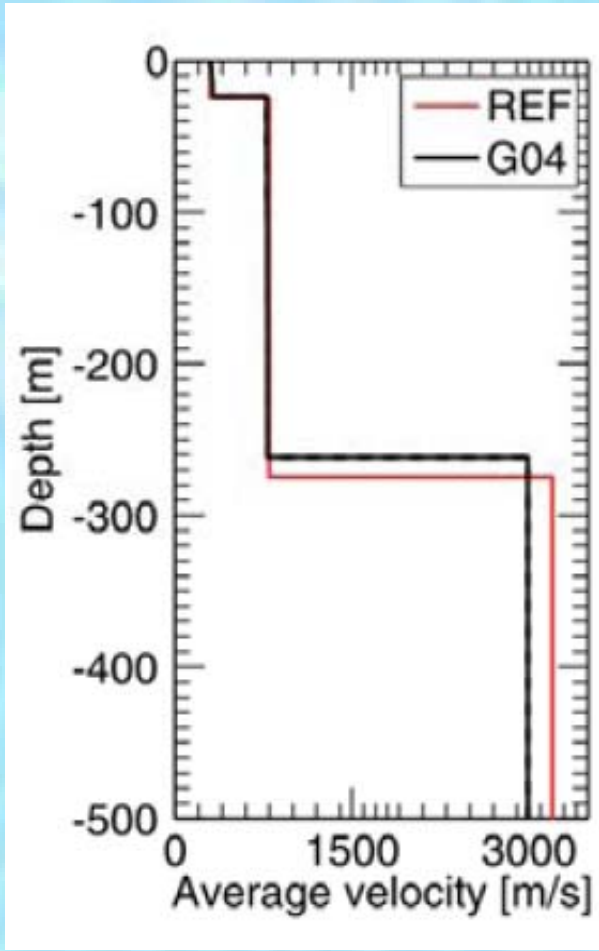
Importance of geological info

Synthetic Dataset N101





Synthetic Dataset N104



Remarks

- Processing techniques lead to similar results
- Passive measurements allow deep characterization
- Active data improve resolution and reliability
- Robust estimate of average velocities (e.g. $V_{S,30}$)
- Due care in using ReMi (additional active data?)
- Inversion with higher modes if necessary
- Inverse methods → a-priori info welcome
- Common basic rules to check results
  - Wavelengths vs array length or size
  - Depths vs available wavelengths
    - Maximum depth ($z_{max} \approx$ ½-1/3 λ_{max})
    - Resolution for shallow layers ($Thk_1 >$ ½-1/3 λ_{min})

Objectives in S4 – Task 3

- V_S profile
- Techniques for Surface Wave analysis?
- Need for more tests in well characterised sites? Tests in a common site ?
- Common exercises on same experimental dataset ?
- Test few “complex” sites or many “simple” sites?
- Targets? ($V_{S,30}$; V_S profile to bedrock; …)
- Choice of sites: logistics, accessibility, space for testing, geological info, …
- Archive of raw and processed data?