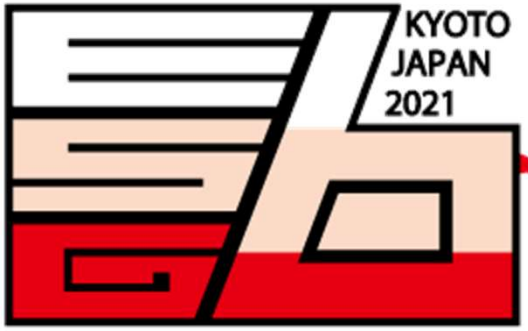

THE 6TH IASPEI / IAEE INTERNATIONAL SYMPOSIUM:

THE EFFECTS OF SURFACE GEOLOGY ON SEISMIC MOTION

AUGUST, 2021 KYOTO, JAPAN

31st August, 2021

IMPROVING THE STATE OF THE PRACTICE IN SURFACE WAVE ANALYSIS FOR SEISMIC SITE CHARACTERIZATION

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ToC

- The Interpacific Guidelines
- Blind test results
- Experimental Databases
- Final remarks

The guidelines for surface wave analysis of the Interpacific project

Bull Earthquake Eng
DOI 10.1007/s10518-017-0206-7

ORIGINAL RESEARCH PAPER

Guidelines for the good practice of surface wave analysis: a product of the InterPACIFIC project

Sebastiano Foti[1] · Fabrice Hollender[2] · Flora Garofalo[1] · Dario Albarello[3] · Michael Asten[4] · Pierre-Yves Bard[5] · Cesare Comina[6] · Cécile Cornou[5] · Brady Cox[7] · Giuseppe Di Giulio[8] · Thomas Forbriger[9] · Koichi Hayashi[10] · Enrico Lunedei[3] · Antony Martin[11] · Diego Mercerat[12] · Matthias Ohrnberger[13] · Valerio Poggi[14] · Florence Renalier[15] · Deborah Sicilia[16] · Valentina Socco[1]

Received: 5 October 2016 / Accepted: 30 July 2017

https://link.springer.com/article/10.1007/s10518-017-0206-7

Scope of the guidelines

- 1D
- R-waves
- Fundamental mode
- Target: non-expert users
- Not a Standardization for Execution and Interpretation (several alternatives are adequate)
- Acquisition, Processing, Inversion

  + notes on application to earthquake engineering

- Appendices: advanced topics (array geometries, higher modes, joint inversions, Love waves, ReMi, attenuation and damping)

Philosophy of the guidelines

- A pre-cooked set of rules cannot be defined: the survey has to be designed;
- The design of the survey relies on the knowledge of the surface wave propagation features;
- The quality of the results relies on the quality of the data;
- The capability to assess the respect of the method assumptions is of paramount importance;
- A good professional result means also a well organised workflow and an informative final report with a clear assessment of the quality of the obtained results.

Usual assumptions

- Horizontally layered medium (no lateral variation)
- Only plane Rayleigh waves (far field: body waves contribution negligible)
- Fundamental mode is dominant

It is very important to verify they are consistent with reality

Assumption can be relaxed (but not an easy task)

Some critical issues

- Spatial resolution
- A-priori hypothesis
- Non-uniqueness
- Higher modes
- Lateral variations (1D model → pseudo 2D)

See also:

Guidelines for the good practice of surface wave analysis:
a product of the InterPACIFIC project

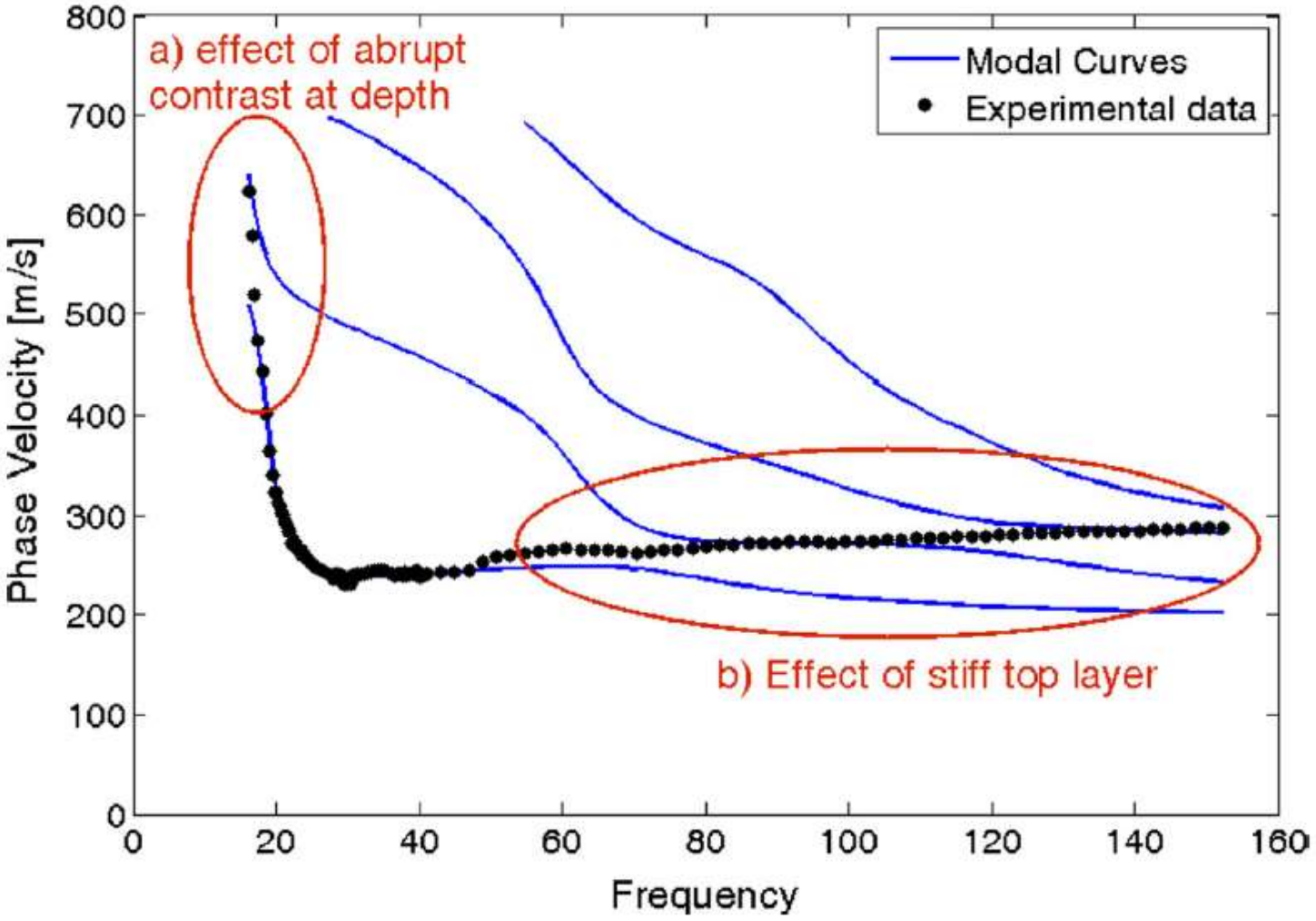
Bull Earthquake Eng DOI 10.1007/s10518-017-0206-7

APPENDICES

(electronic supplement material)

https://static-content.springer.com/esm/art%3A10.1007%2Fs10518-017-0206-7/MediaObjects/10518_2017_206_MOESM1_ESM.pdf

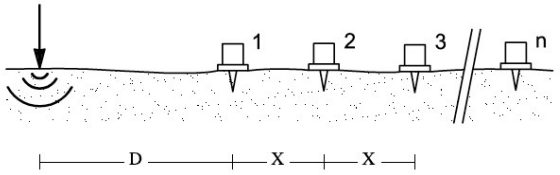
Apparent dispersion curve (lack of spectral resolution)



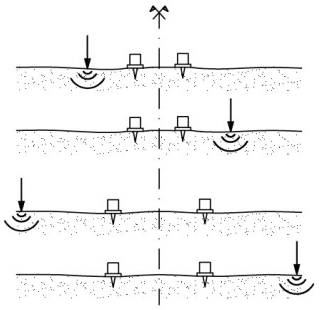
SWM techniques for near surface characterization

Active methods

Multistation:
f-k, τ-p, MASW, …

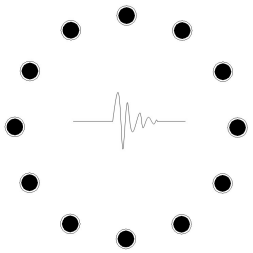


Two-station (SASW)



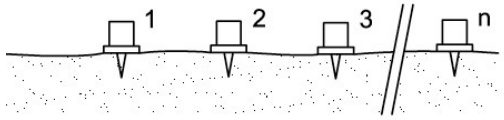
Passive methods

Spatial Array:
Spatial Autocorrelation
(SPAC, ESAC), f-k spectra
(FDBF, MLM, Music), ...



Receivers:
3C Geophones
0.2 – 1Hz nat. freq.

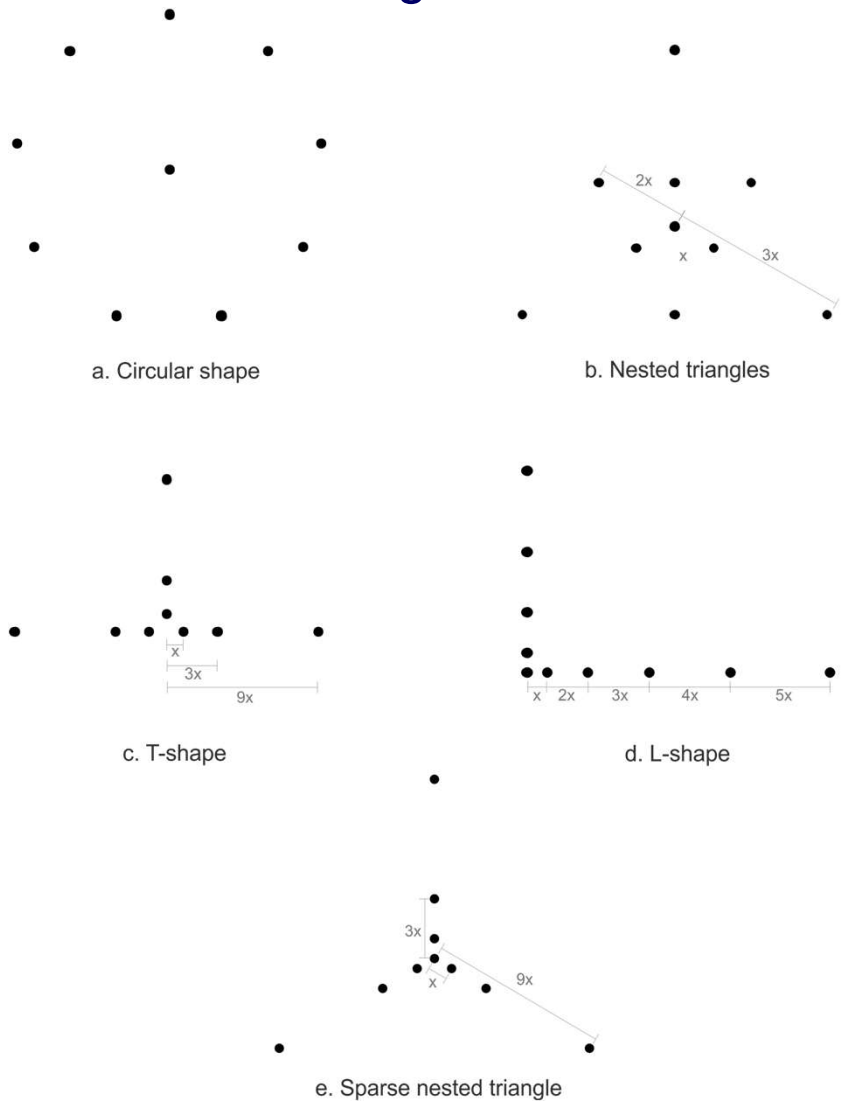
Linear array (ReMi)



Warning

Survey design for Ambient Vibration Analysis

Usual geometries



Minimum: 4 receivers
Suggested: 8-10 receivers

Usually multiple arrays (especially if few receivers are used)

Aperture of the larger array equal al least the desidered investigation depth (better twice)

Minimum distance in the smaller array equal to desidered resolution of shallow layers

ToC

- The Interpacific Guidelines
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InterPacific Project - Journal Publications

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

1) InterPACIFIC project: Comparison of invasive and non-invasive methods for seismic site characterization. Part I: Intra-comparison of surface wave methods

Garofalo et al. (2016a)

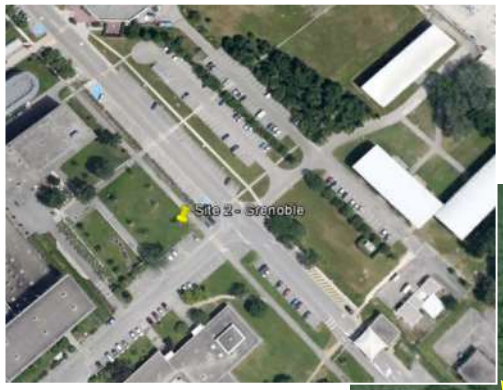
F. Garofalo [a,1], S. Foti [a,*], F. Hollender [b], P.Y. Bard [c], C. Cornou [c], B.R. Cox [d], M. Ohrnberger [e], D. Sicilia [f], M. Asten [g], G. Di Giulio [h], T. Forbriger [i], B. Guillier [c], K. Hayashi [j], A. Martin [k], S. Matsushima [l], D. Mercerat [m], V. Poggi [n], H. Yamanaka [o]

2) InterPACIFIC project: Comparison of invasive and non-invasive methods for seismic site characterization. Part II: Inter-comparison between surface-wave and borehole methods

Garofalo et al. (2016b)

F. Garofalo [a,1], S. Foti [a,*], F. Hollender [b], P.Y. Bard [c], C. Cornou [c], B.R. Cox [d], A. Dechamp [e], M. Ohrnberger [f], V. Perron [b], D. Sicilia [g], D. Teague [d], C. Vergniault [g]

Interpacific Project: borehole and surface seismic tests



Geol. Info.: Stiff Soil

Alluvial deposits with of few tens meters then lacustrine deposits of several hundreds meters

Geol. Info.: Soft Soil

Alluvial deposits

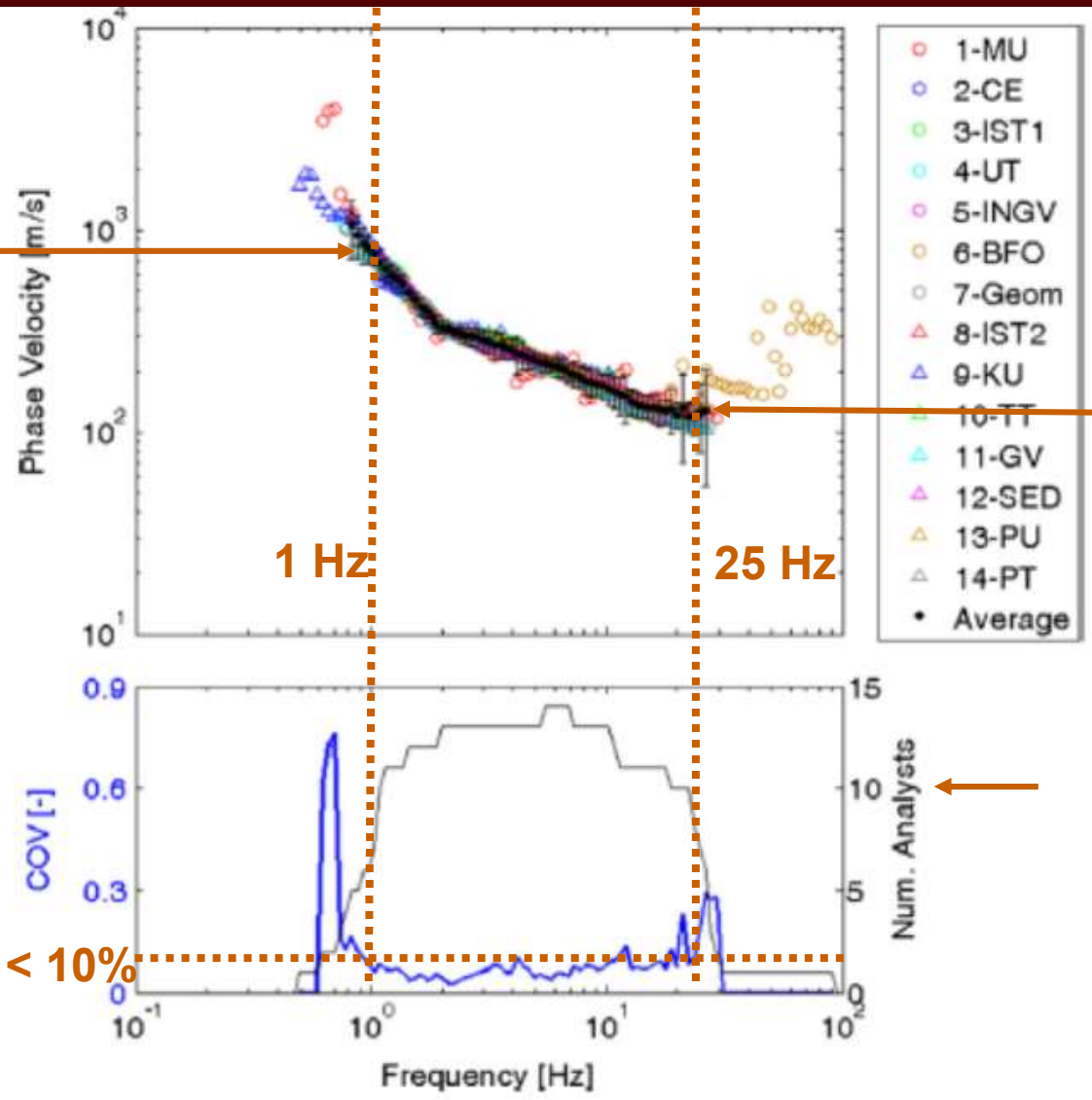
Geol. Info.: Hard Rock

Limestone

Mirandola Site – Dispersion Comparison

$\lambda = V/f$

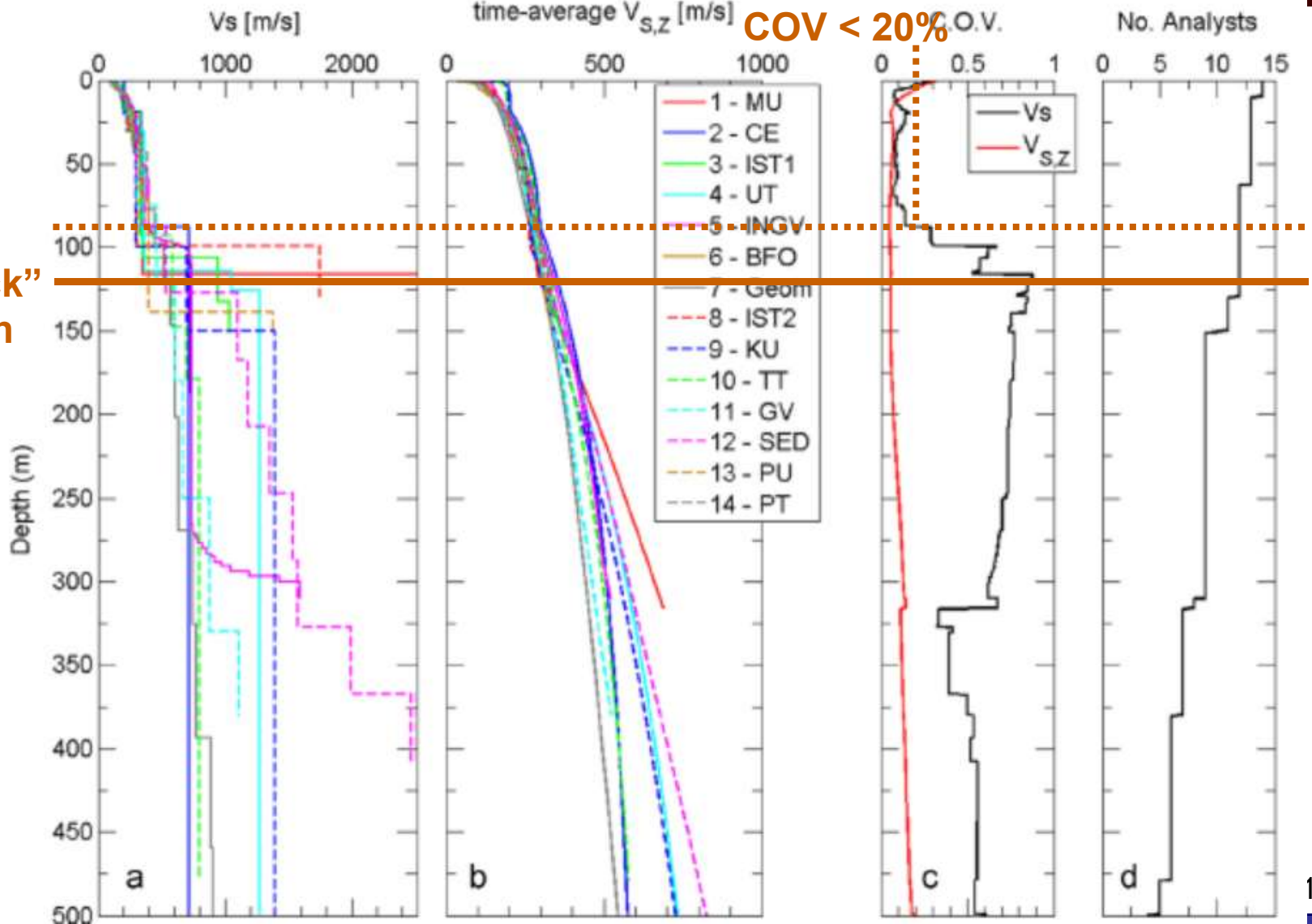
λ_{max} ~ 800 m
Remember …
max circular array aperture 800 m



λ_{min} ~ 4 m
Spatial aliasing limit based on 2 m MASW receiver spacing

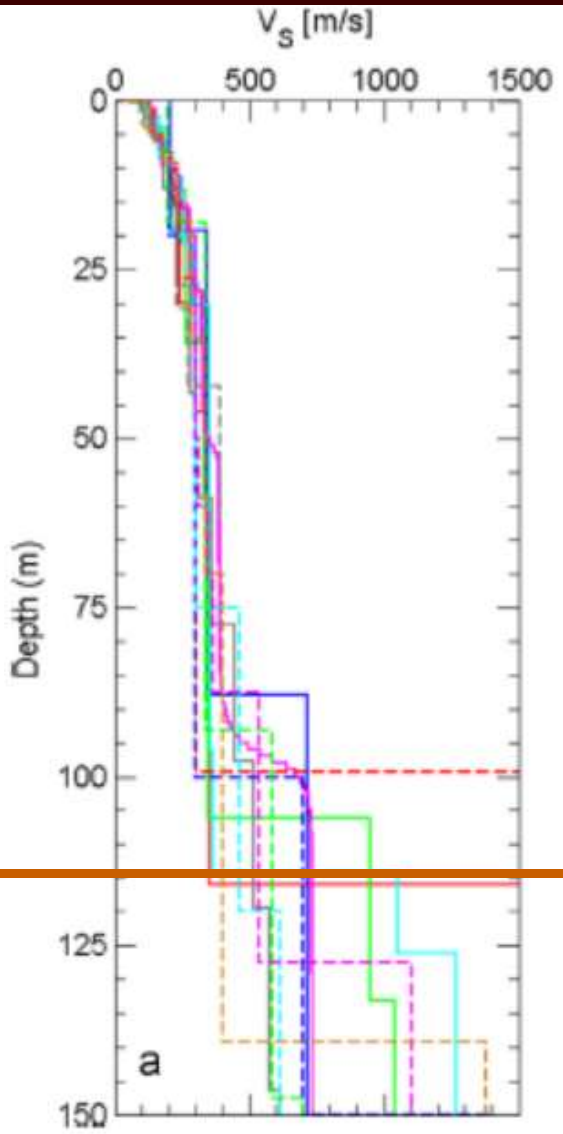
COV < 10%

Mirandola Site – Vs Profiles – 500 m



~ "Rock" Depth

Mirandola Site – Vs Profiles – 150 m



~ "Rock" Depth

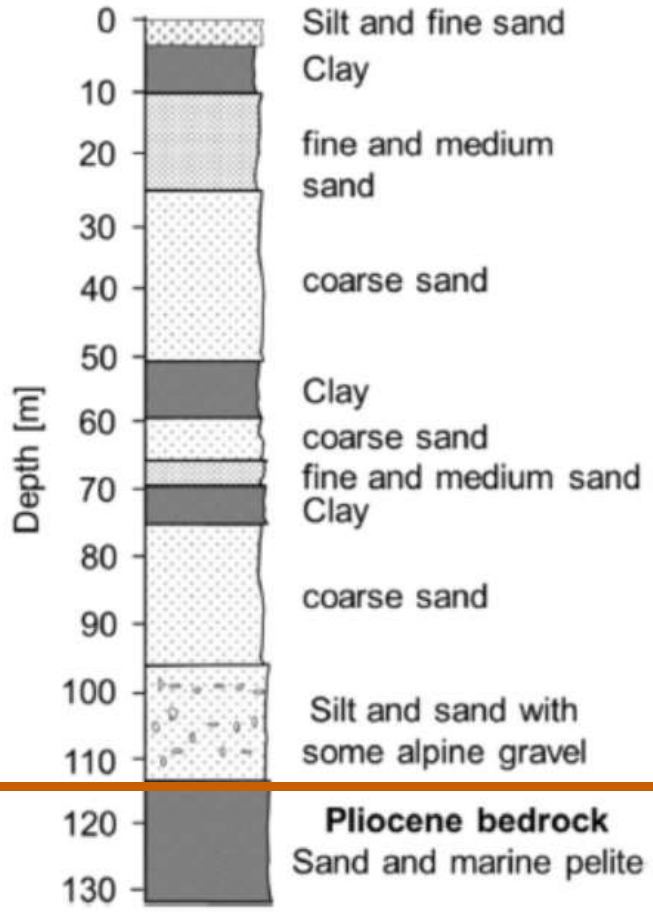
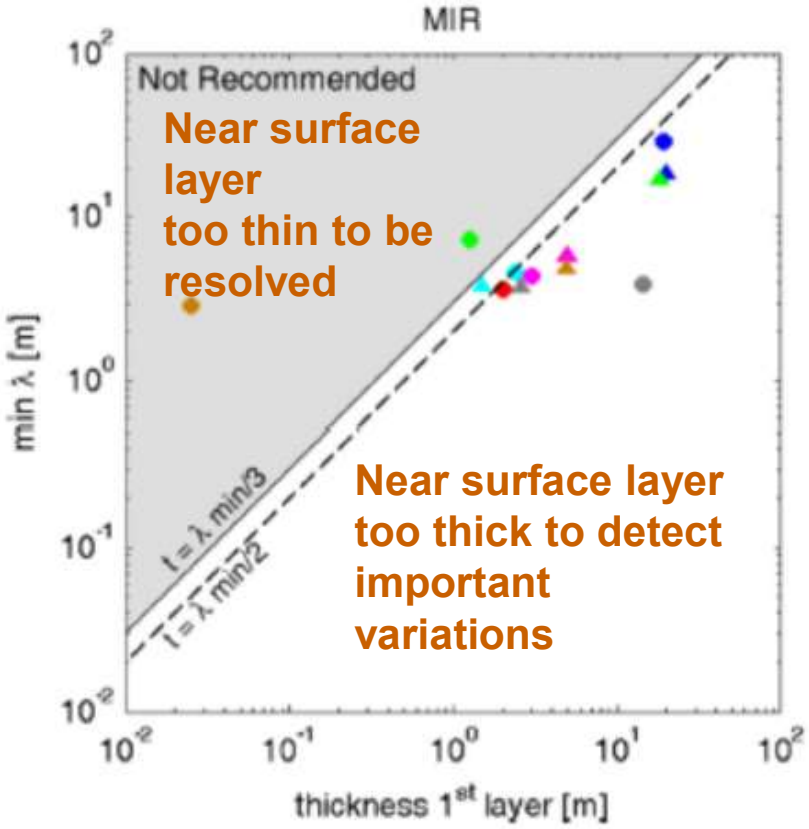


Fig. 1. Soil stratigraphy at Mirandola site (MIR).

Mirandola Site – λ_{min} and λ_{max}

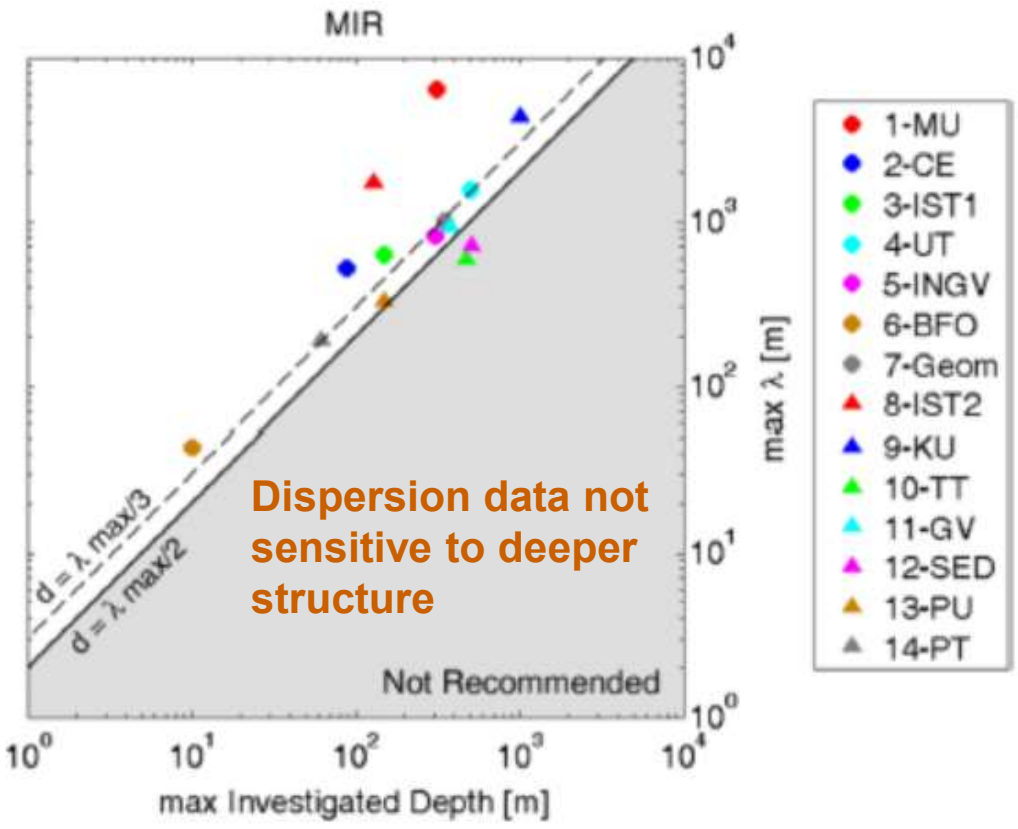
Resolution of shallow layers

$$h_{min} \approx \lambda_{min}/2$$



Investigation depth

$$z_{max} \approx \lambda_{max}/2$$

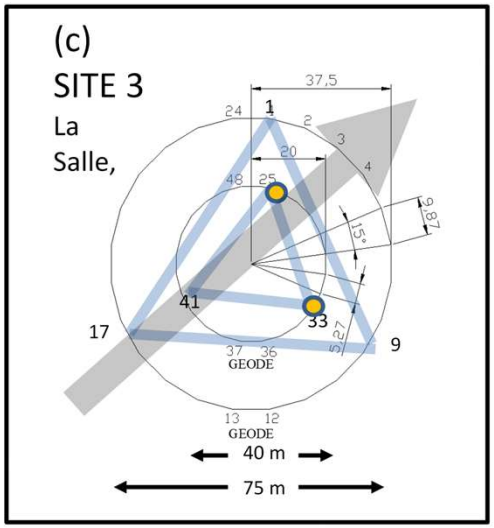


AVA: Cosmos blind test on sparse arrays

Check the capabilities of Ambient Vibration Analysis (Passive surface wave methods) for different number of receivers (starting with 2 receivers and progressively increasing the number)

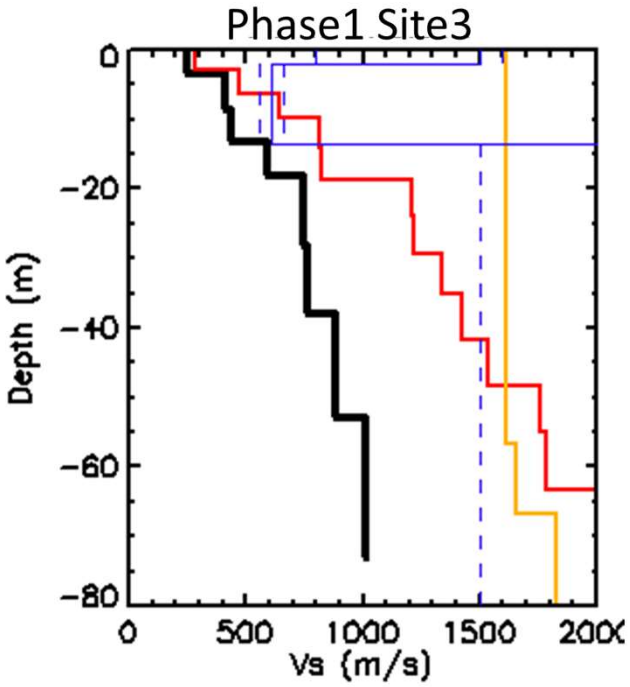
4 Sites – 34 Analysts

Conclusions: subject to a sufficient azimuthal distribution of seismic noise sources, the use of sparse arrays is sufficient for accurate estimates, however the use of only 2 receivers may lead to significant errors when sources are not well azimuthally-distributed

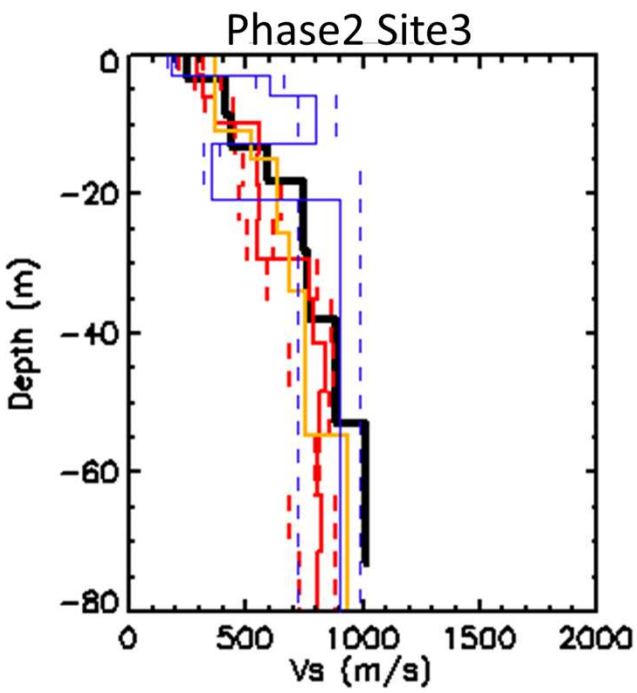


(Asten et al., 2021)

2 receivers



6 receivers



Databases of Surface Wave experimental data

Useful for verification and validation of the tools used for surface wave analysis also against the results of independent evaluations of the shear wave velocity profiles obtained with borehole (invasive) seismic test:

- for non-expert users of commercial codes to check the correct use of the code and also the performance of the code itself.
- for code developers as a benchmark for the validation.

- Interpacific blind test (the full set of raw experimental data is available on the Geopsy website)
- Cosmos blind test (the full set of raw experimental data is available on the USGS website @ doi.org/10.5066/P9IA54PL)
- DesignSafe data repository
- PoliTO Surface Wave Database

ToC

- The Interpacific Guidelines
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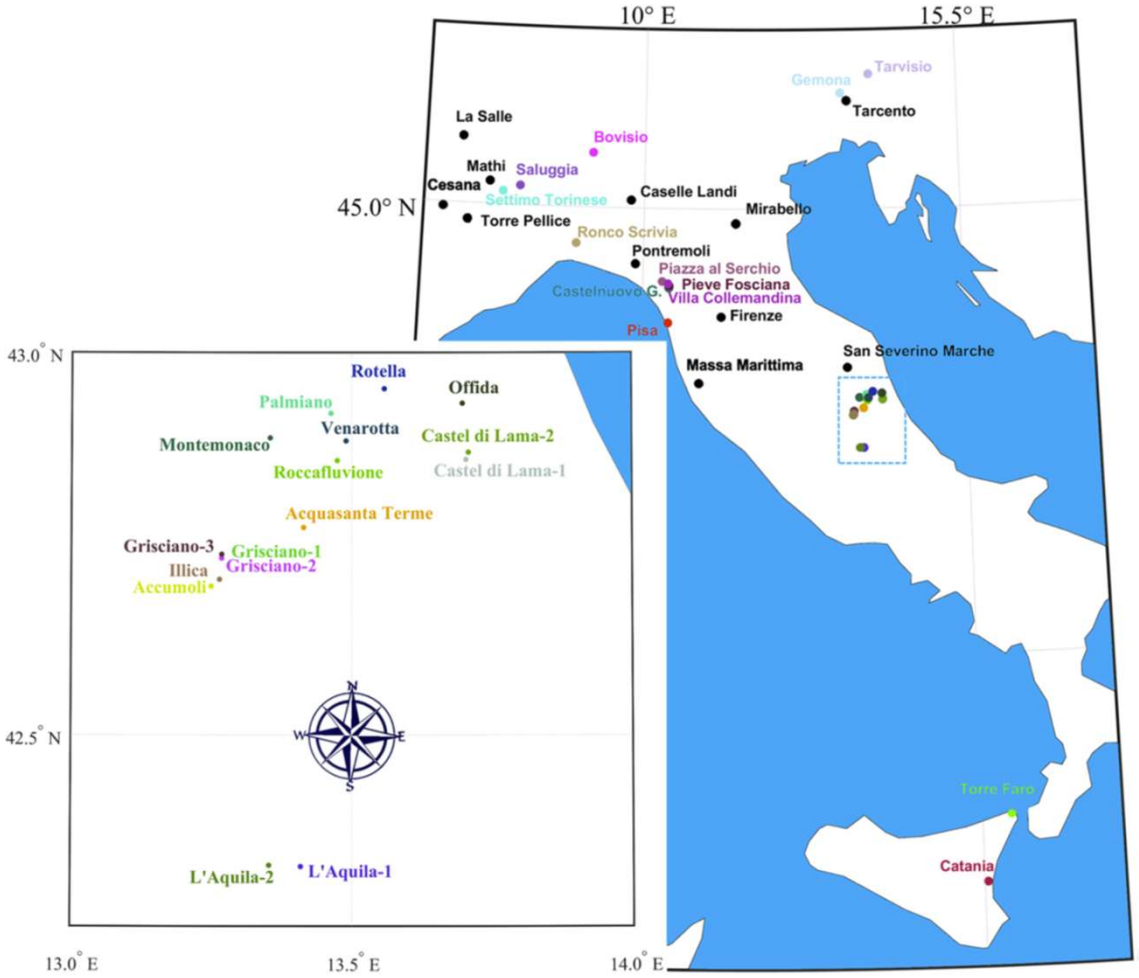
PSWD – PoliTO Surface Wave Database



Flat file database

71 sites:

- EDC (Fundamental mode)
- V_S profile

(Interpretation of Surface Wave data with in-house software)

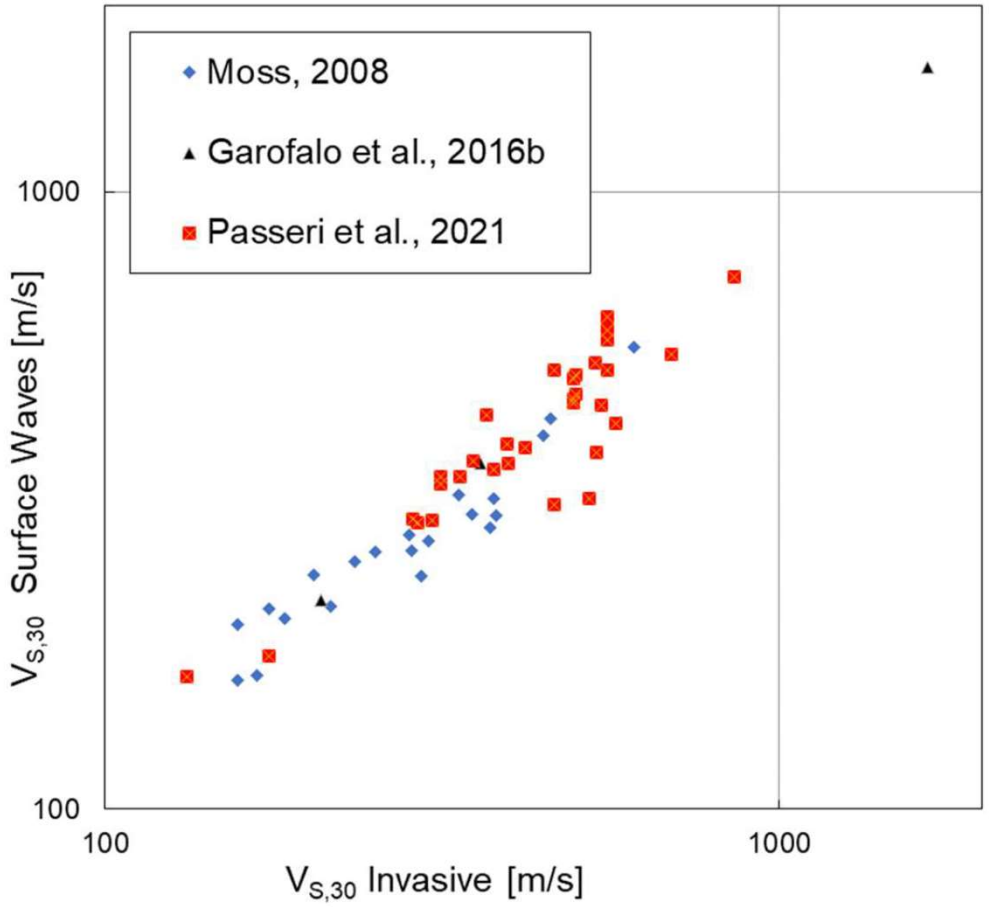
Independent V_S profile from invasive tests available for 44 sites

Passeri et al., 2021
Open Access Paper –
Bulletin of Earthquake Engineering

https://doi.org/10.1007/s10518-021-01069-1

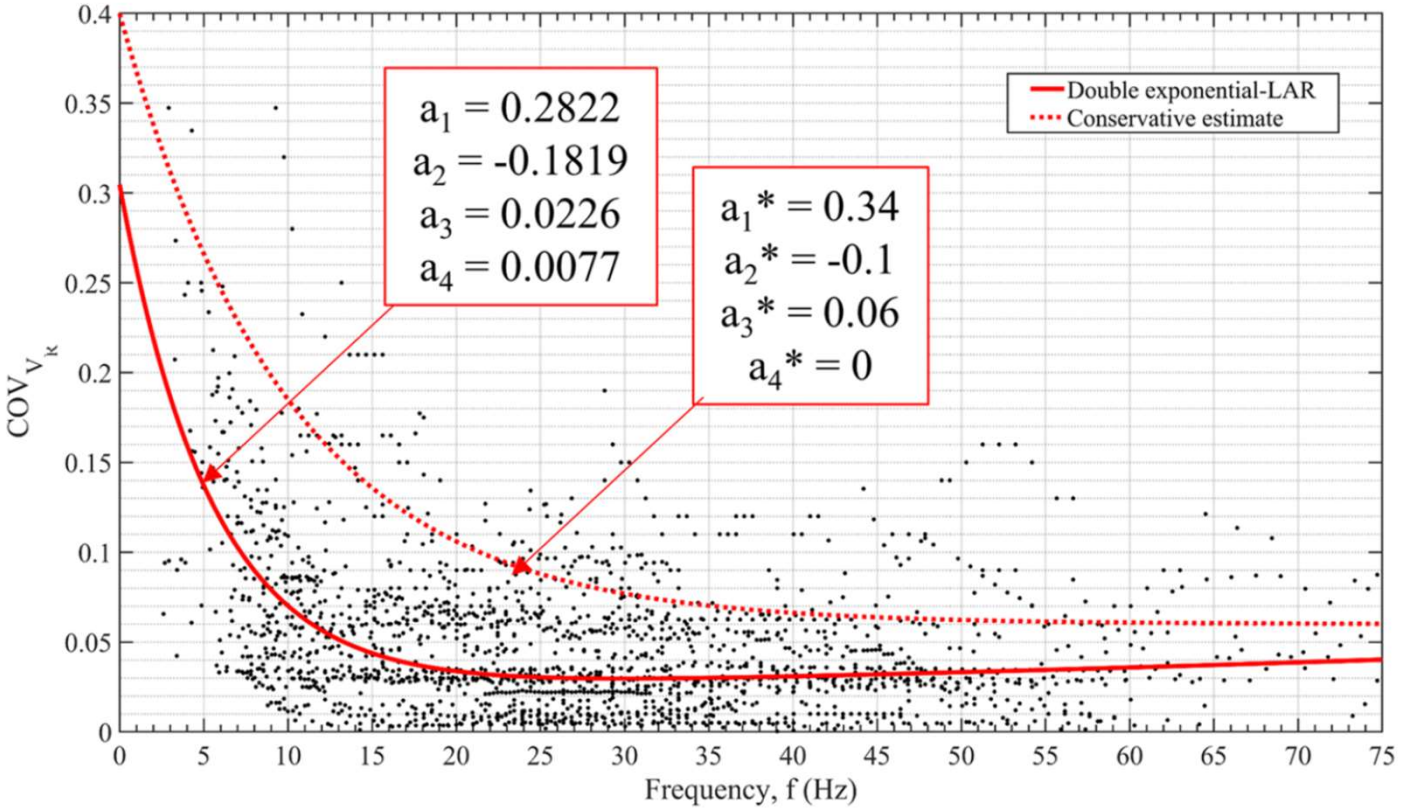
PSWD – PoliTO Surface Wave Database

Surface waves analysis vs. invasive (borehole) seismic methods



PSWD – PoliTO Surface Wave Database

Empirical relationship for the estimate of experimental uncertainties
(useful when insufficient experimental data prevent a direct estimate)

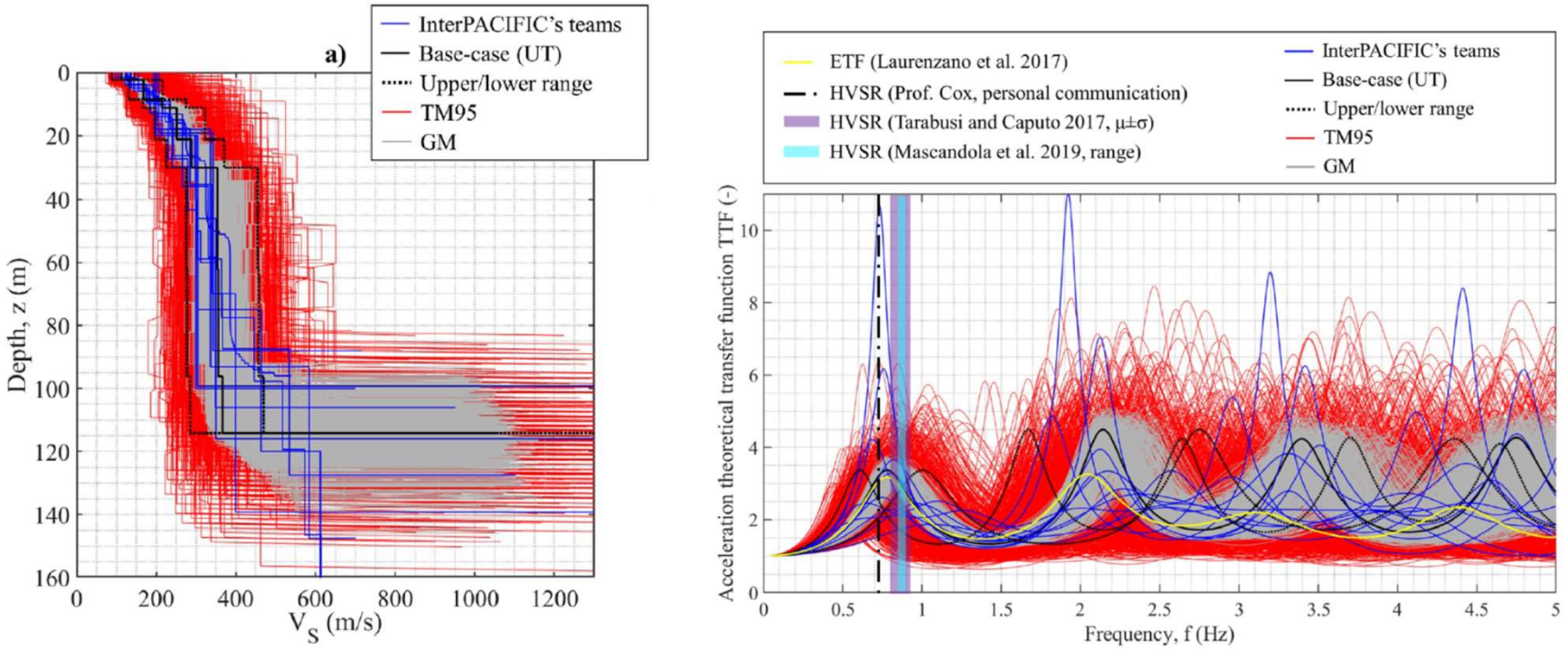


$$\mathrm{COV}_{V_R}(f) = a_1 e^{a_2 f} + a_3 e^{a_4 f}$$

(Passeri et al., 2021)

PSWD – PoliTO Surface Wave Database

The database has been also used to calibrate a novel geostatistical model for the randomization of shear wave velocity profiles (Passeri et a. 2020 - SDEE)
The model is able to provide representative VS profiles which implicitly honor the site signature from independent dataset (e.g. experimental TF)



(Passeri et al., 2020)

Final Remarks

- SWM are increasingly popular
- Need to improve the standard of the practice
- Guidelines may contribute but are not a substitute for experience and skill of the analyst
- Some issues are still open (e.g. how to deal with higher modes)
- Further efforts are ongoing to provide Guidelines (e.g. COSMOS project on Characterizing Seismic Site Conditions)
- Benchmarking with previous test may help non-experts and code developers → e.g. PSWD database

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Thank you for your attention

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presentation available at

http://www.soilmech.polito.it/news