Analysis of borehole data

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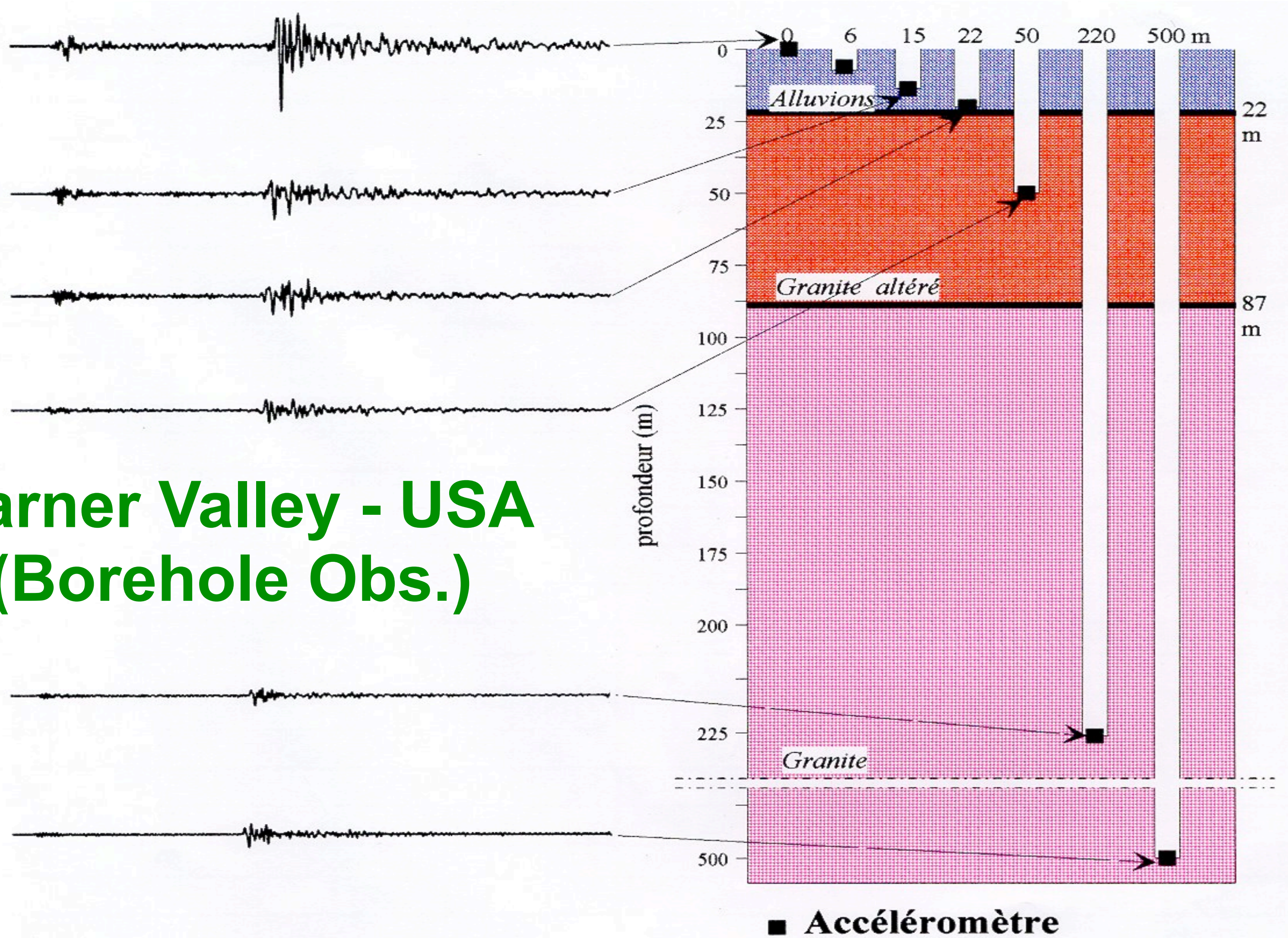
Outline

- Advantages of borehole data
- Difficulties of working with these data
- Understanding linear and nonlinear modeling
- Working proposition?

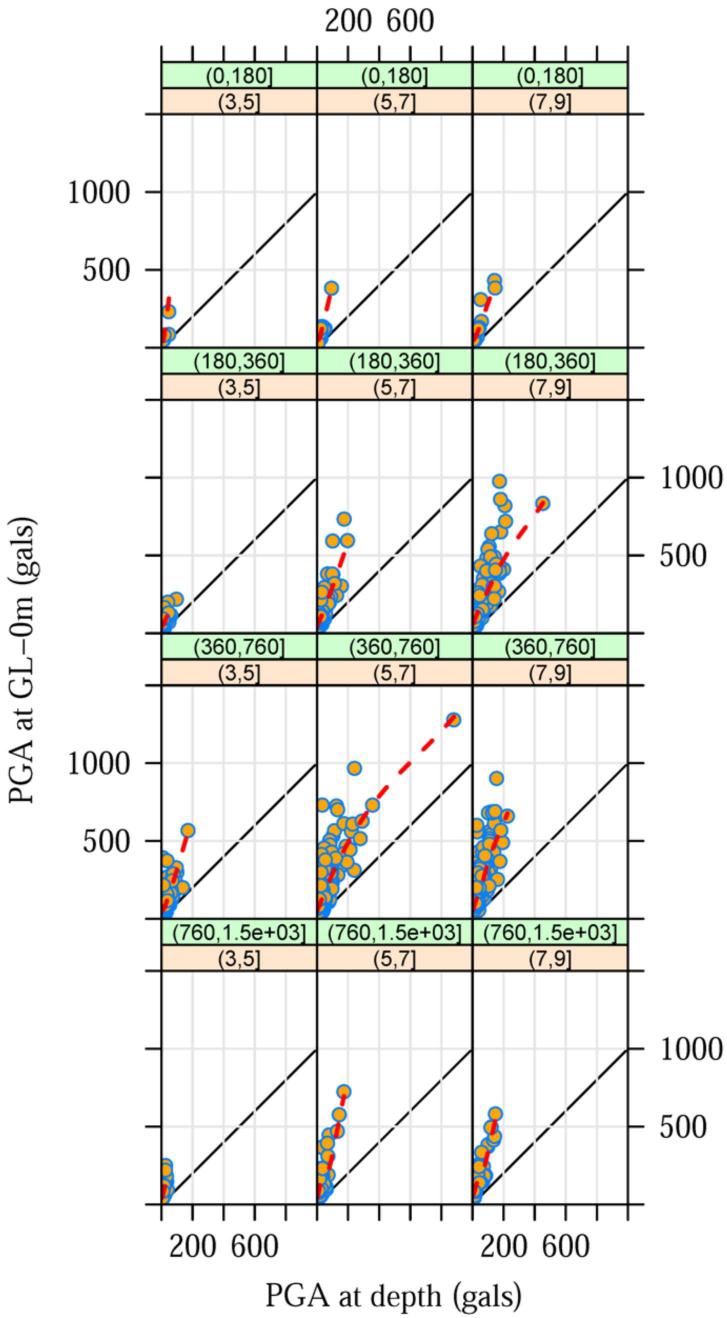
1. Advantages of borehole data



Garner Valley - USA (Borehole Obs.)

Wave propagation from bedrock to surface

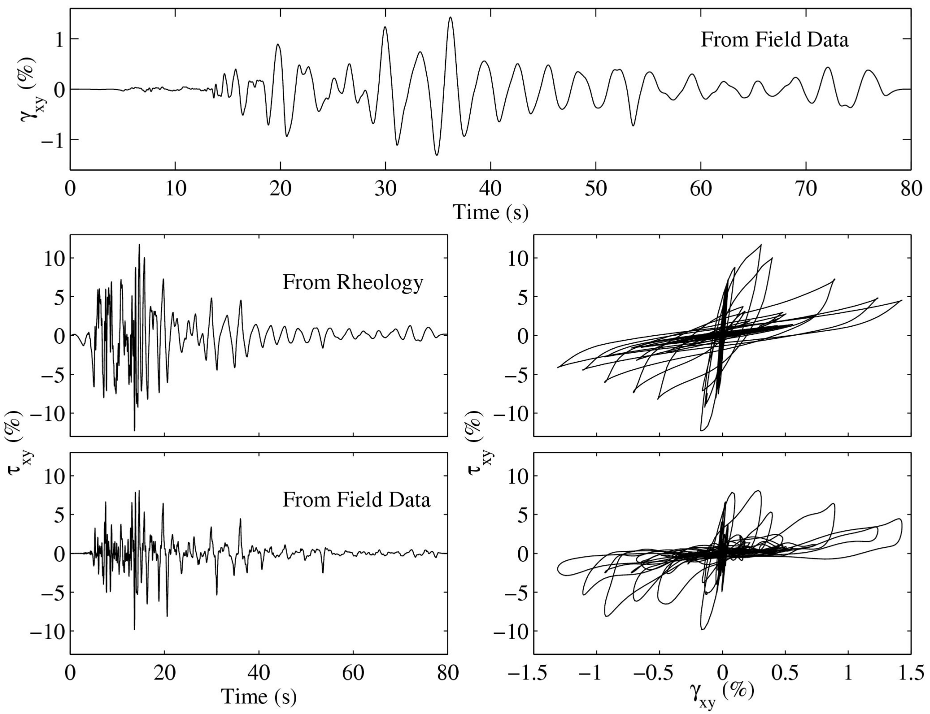
PGA distribution (KiK-net)

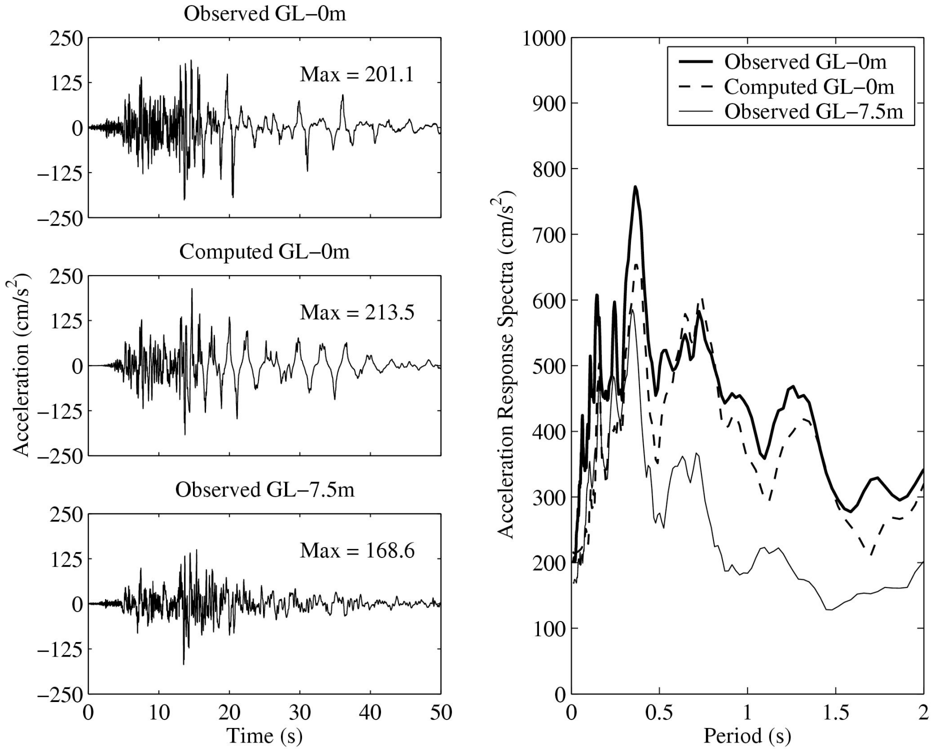


Field data observation of soil nonlinearity onset?

Statistical analysis with respect to magnitude and Vs30

Calibration of soil models



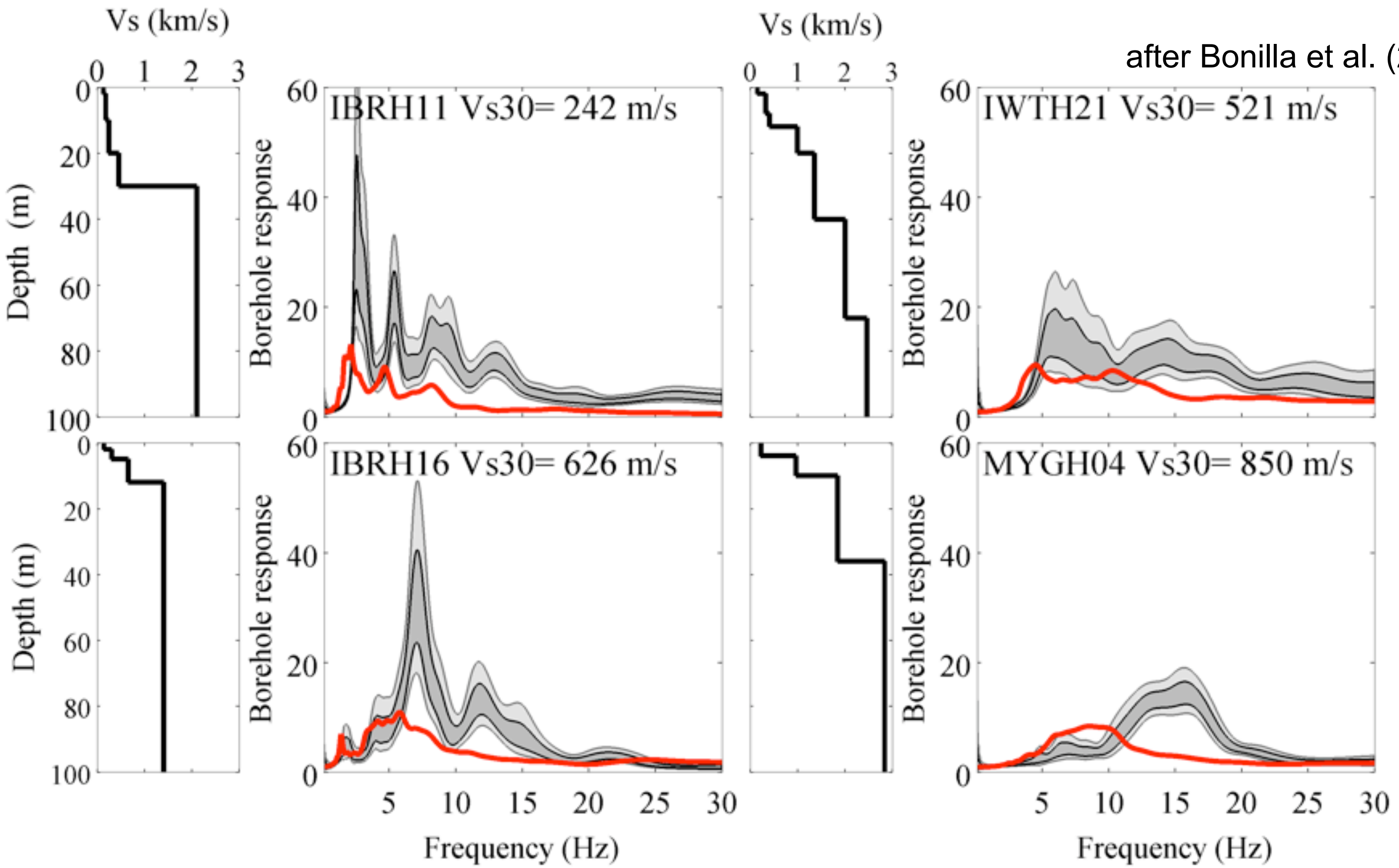


Stress computation from deformation data

Waveform modeling

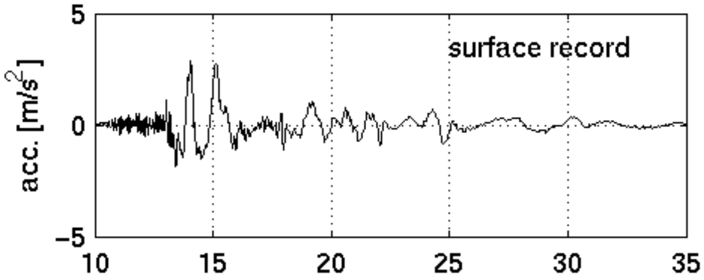
Revealing nonlinear response

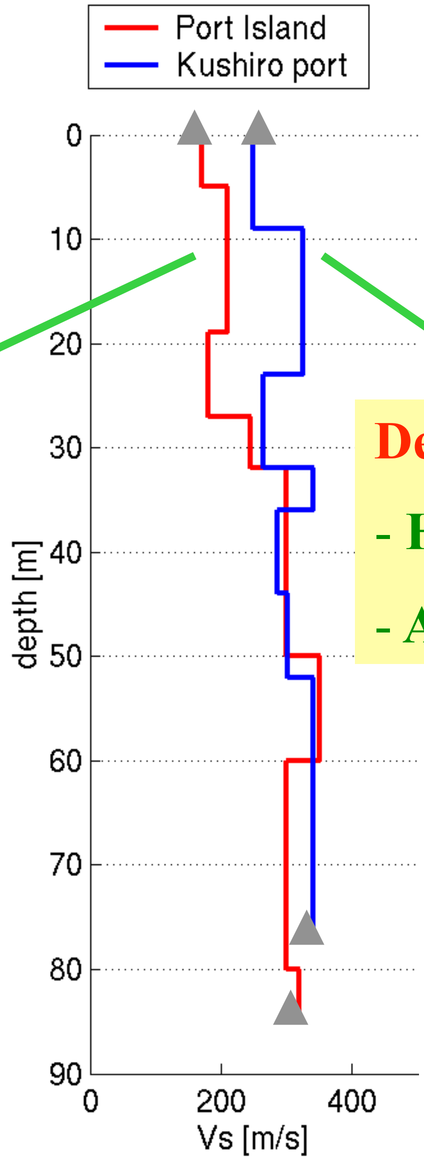
after Bonilla et al. (2011)

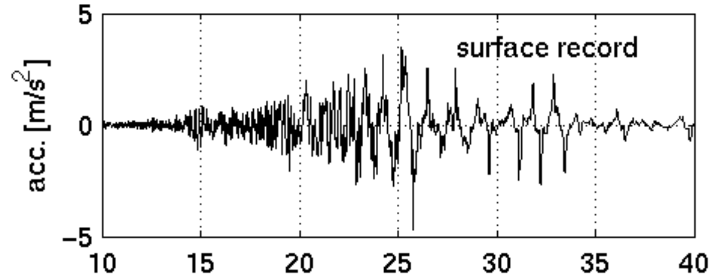


- 2011 Tohoku earthquake data
- Predominant frequency more affected than fundamental
- Affected frequency increases as Vs30 increases

Port Island, Kobe / Kushiro Port







Loose sand => liquefaction

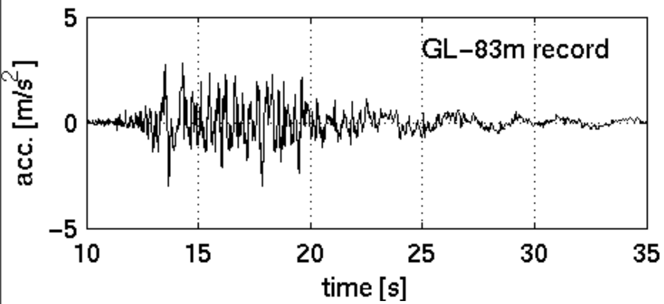
-Lowpass filtering

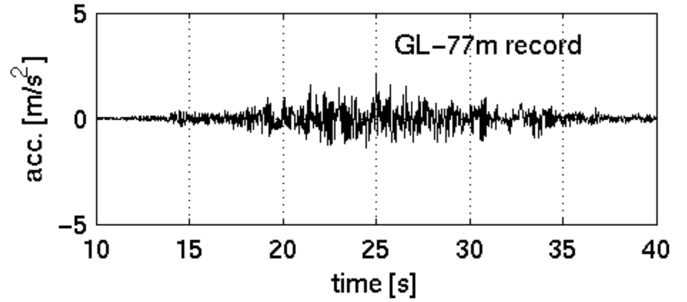
-Deamplification

Dense sand => cyclic mobility

- High frequency peaks

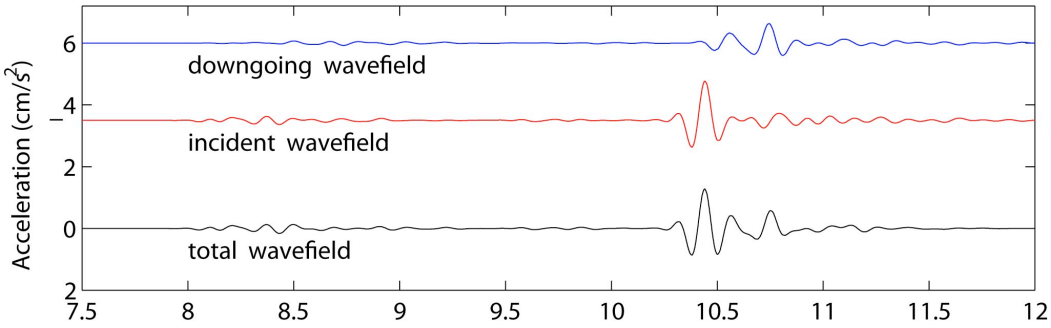
- Amplification



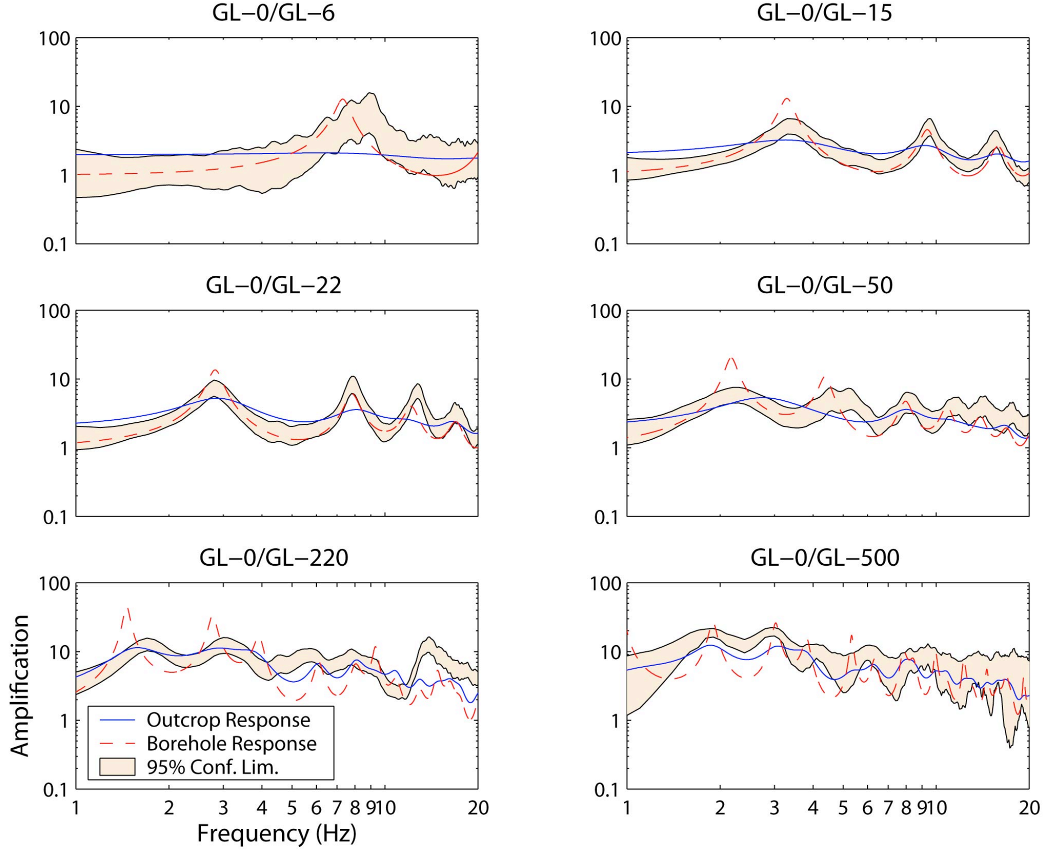


Velocity model is not always enough!

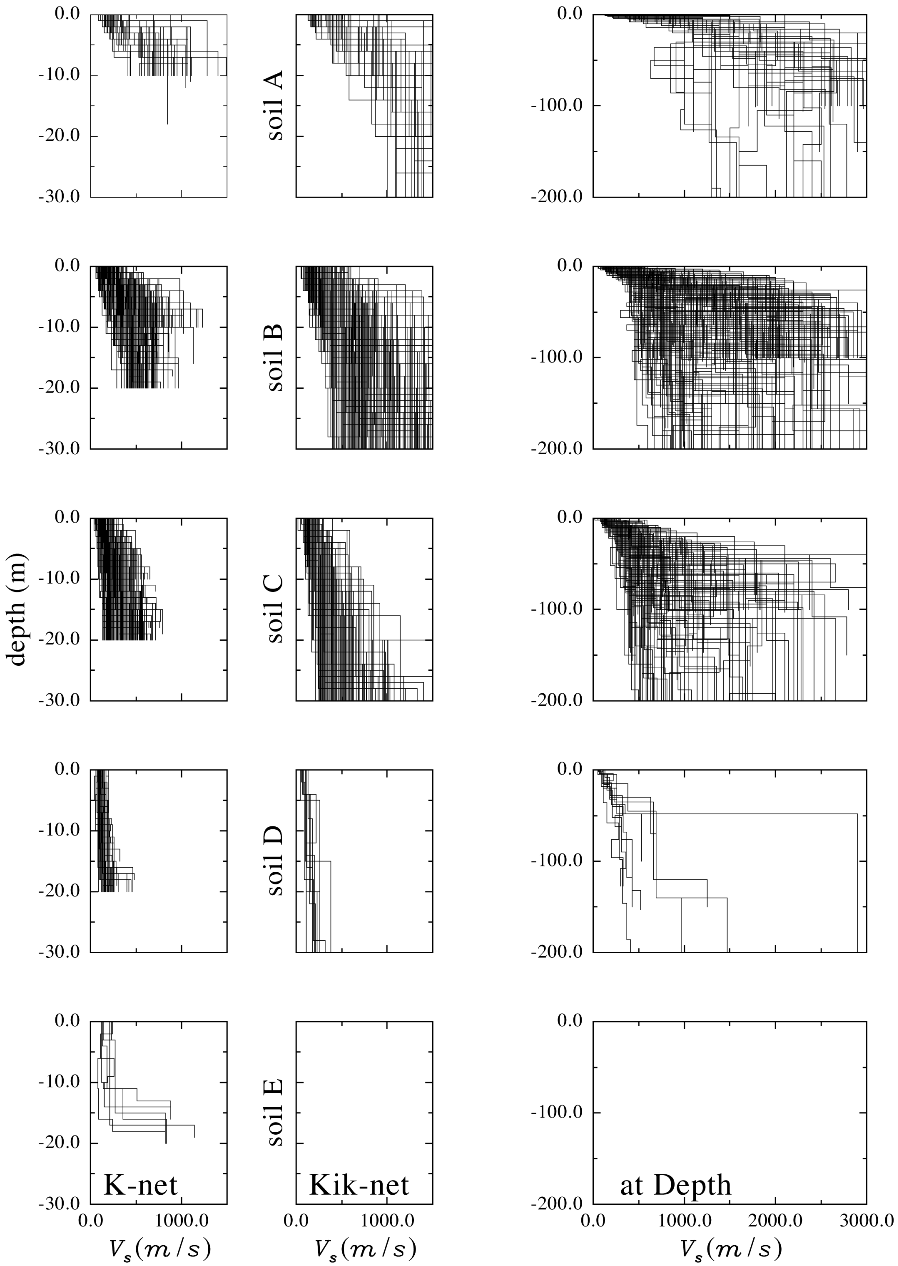
2. Difficulties of borehole data



Downgoing wavefield

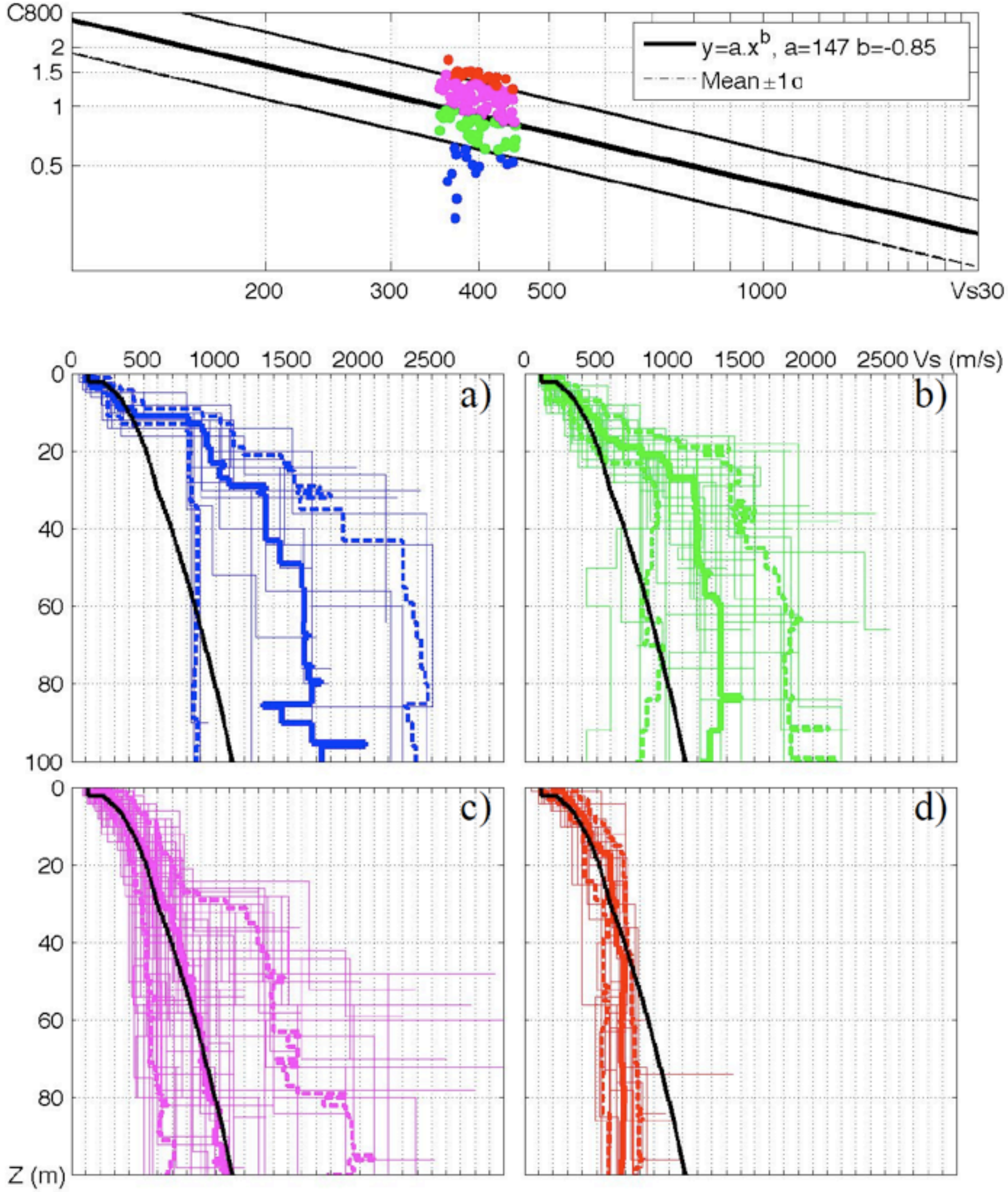


Site response (outcrop response) is not the same as borehole response



Vs30 uncertainty (lack of knowledge of the medium)

- Variability within each soil class is important
- This variability is even larger at depths greater than 30 m
- Is Vs30 enough?
- Not always core sampling, thus no dynamic soil parameters

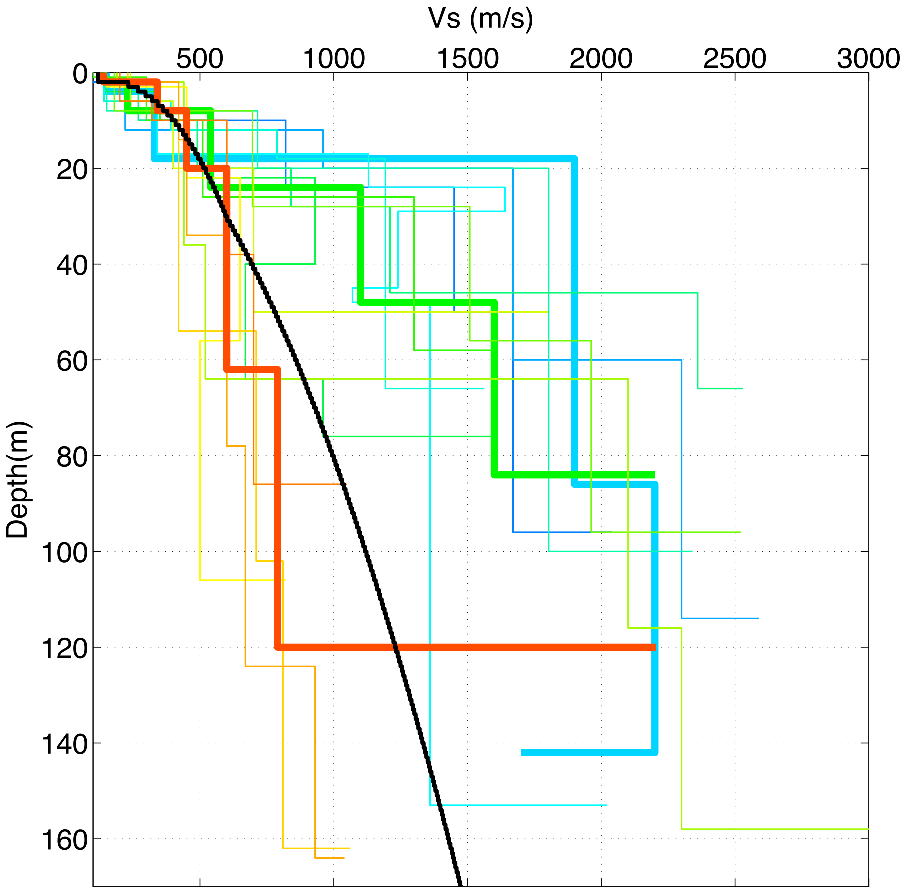


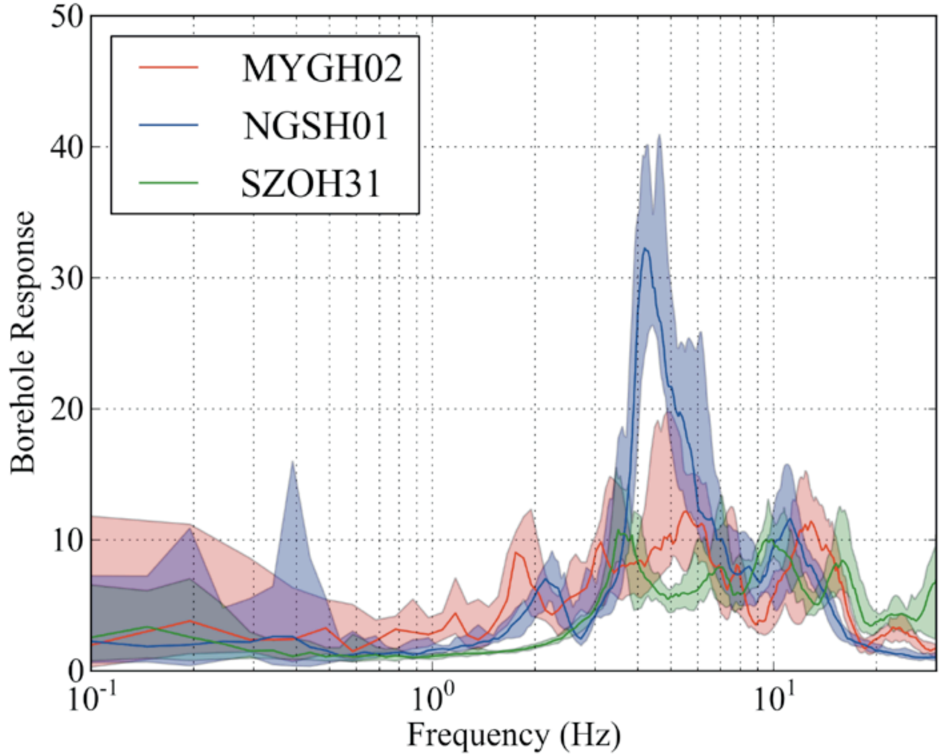
Analysis of KiK-net boreholes

- Similar Vs30 (between 350 and 450 m/s)
- Different velocity distribution at depth
- Different site response
- Is Vs30 enough?

After Regnier et al. (2010)

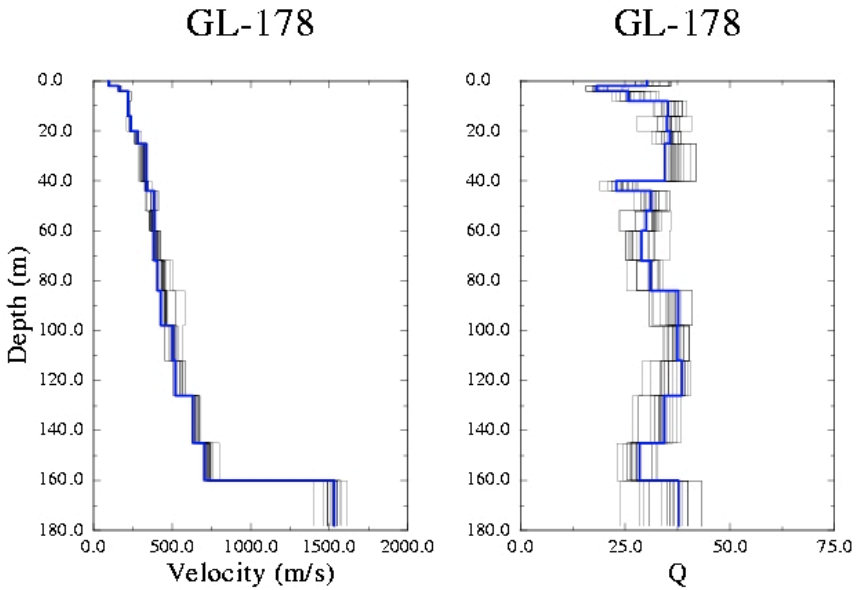
Vs30 = 400 +/- 5 m/s

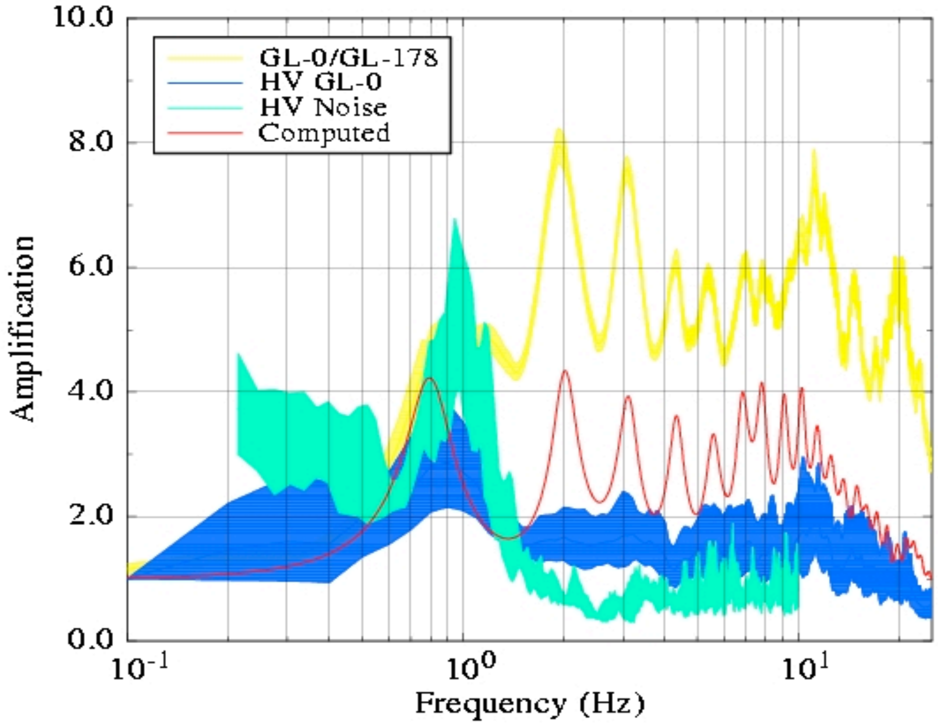


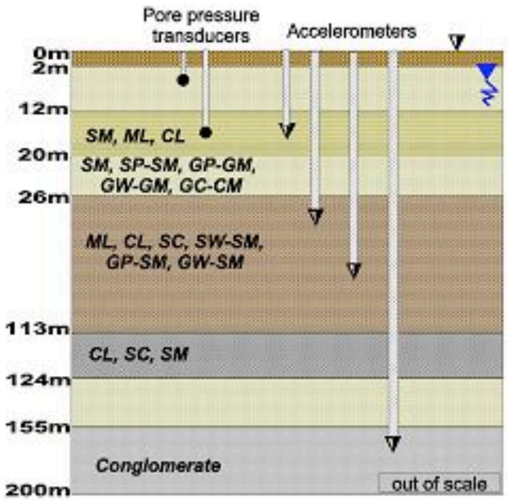


No comments!
The data speak alone

3. We need to know well the linear response (example of the CORSSA array, Greece)

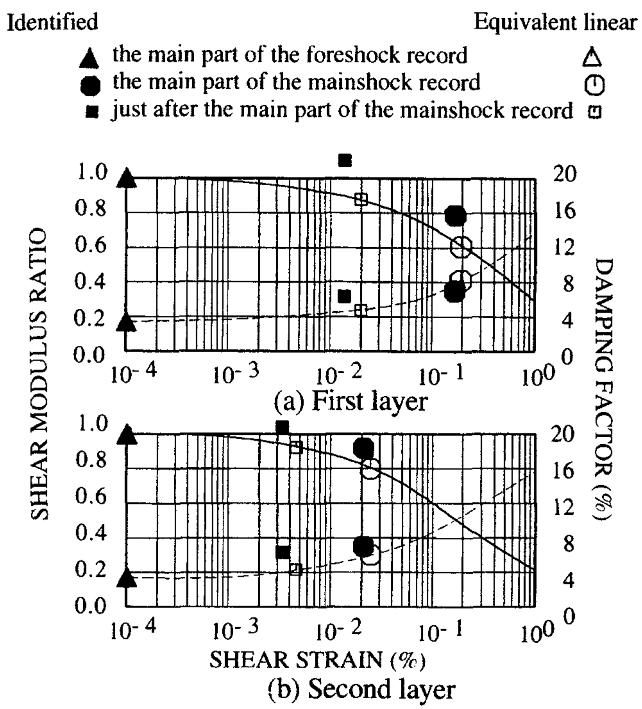




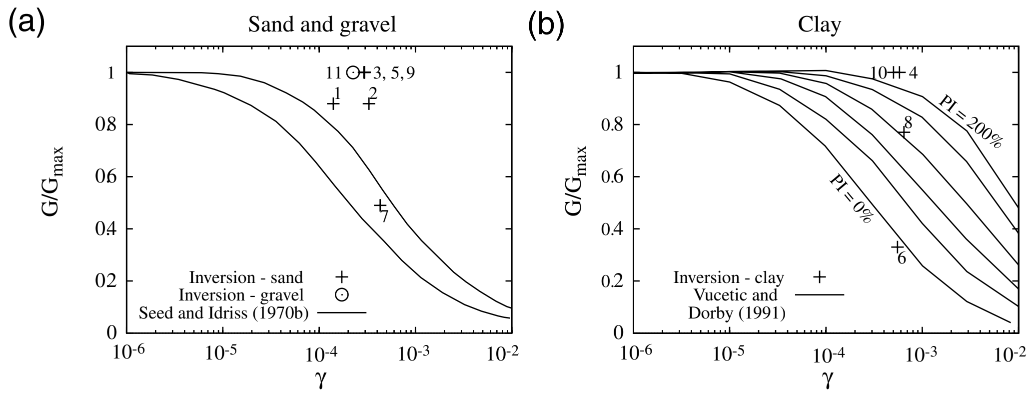


1. H/V spectral ratio (noise data)
2. H/V spectral ratio (earthquake data)
3. Standard spectral ratio (borehole response)
4. Borehole response inversion (velocity, thickness, and Q profiles)

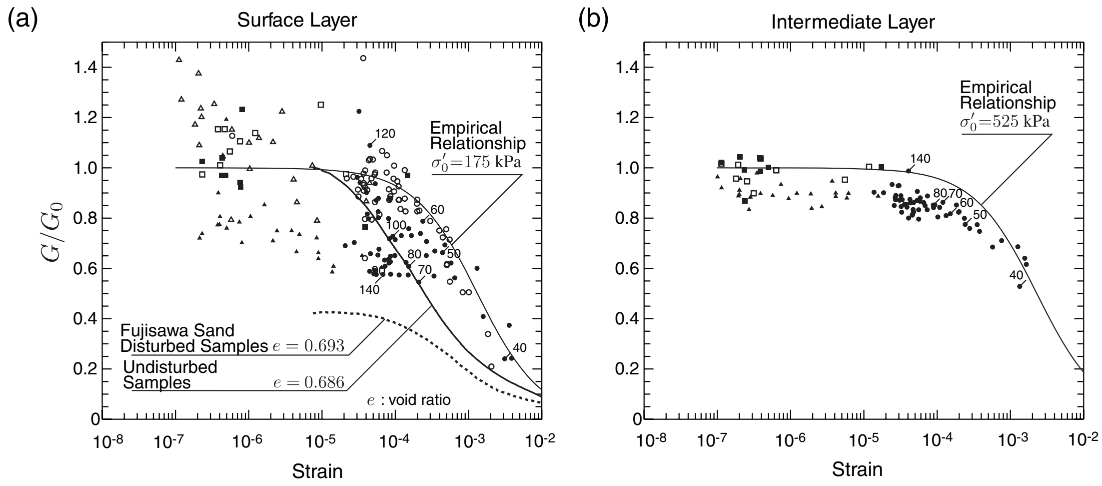
Inverting for nonlinear soil properties



Pioneering work by T. Satoh since the 90's



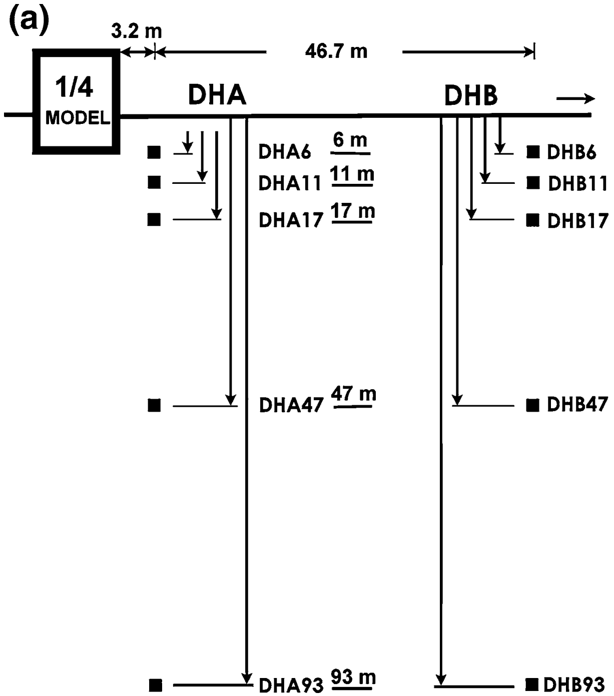
De Martin et al. (2010)

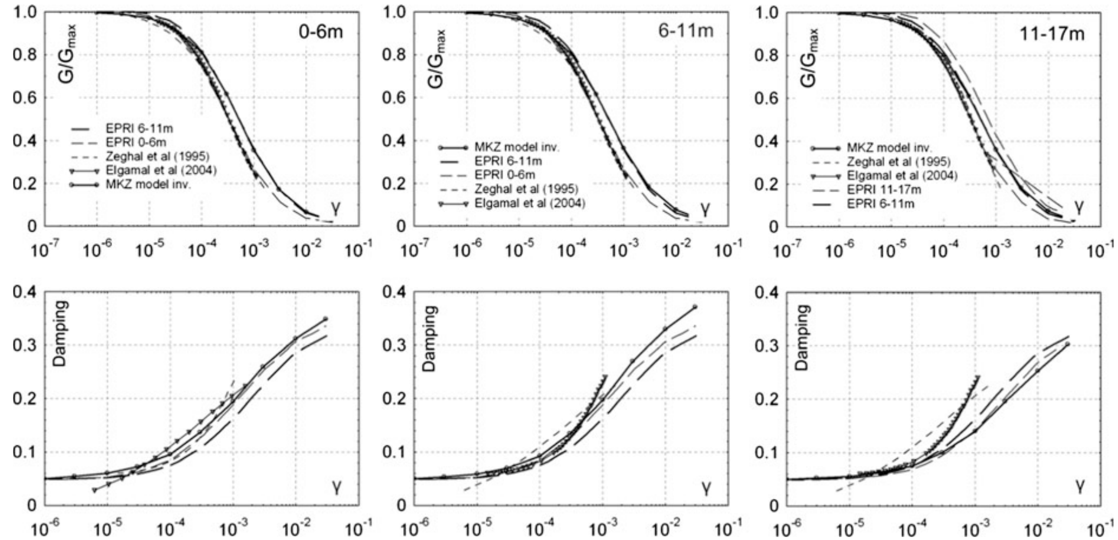


Mogi et al. (2010)

- Use of vertical arrays
- Inversion of G/Gmax only

Inverting for nonlinear soil properties

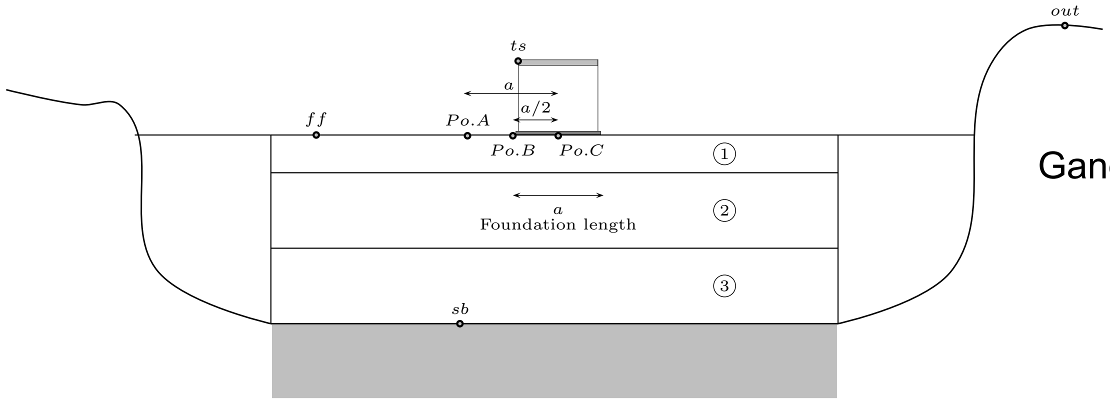




Assimaki et al. (2010)

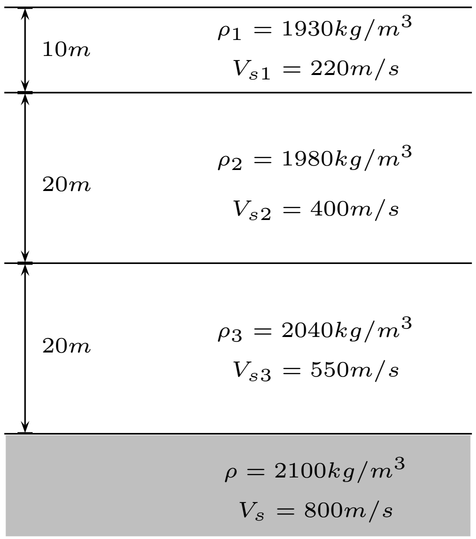
Inverting for G/Gmax and damping ratio

An insight of nonlinear soil response

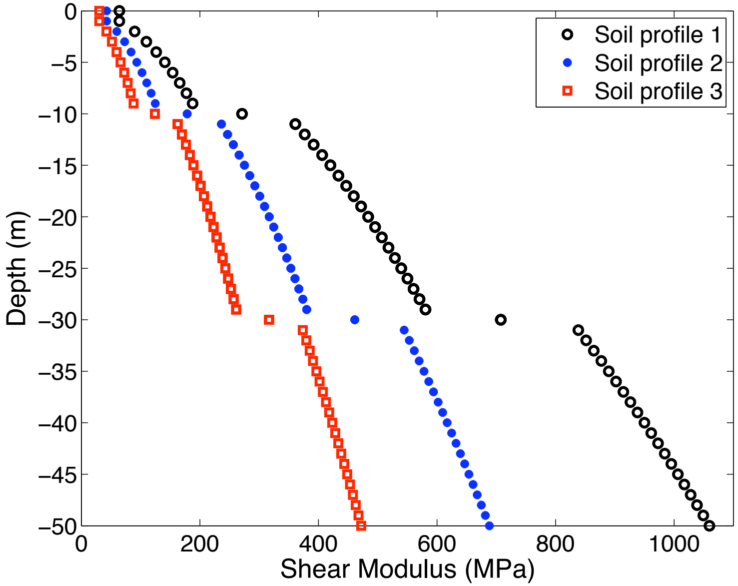


Gandomzadeh (2011)

Soil-structure interaction model



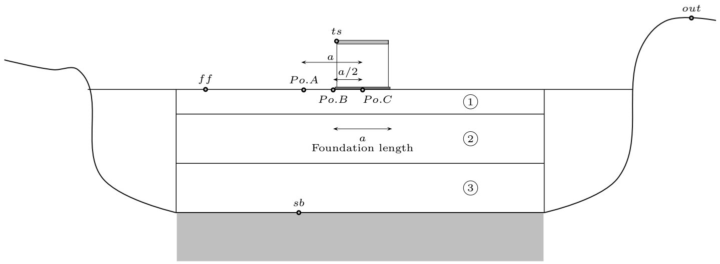
(b) Soil profile (#2)



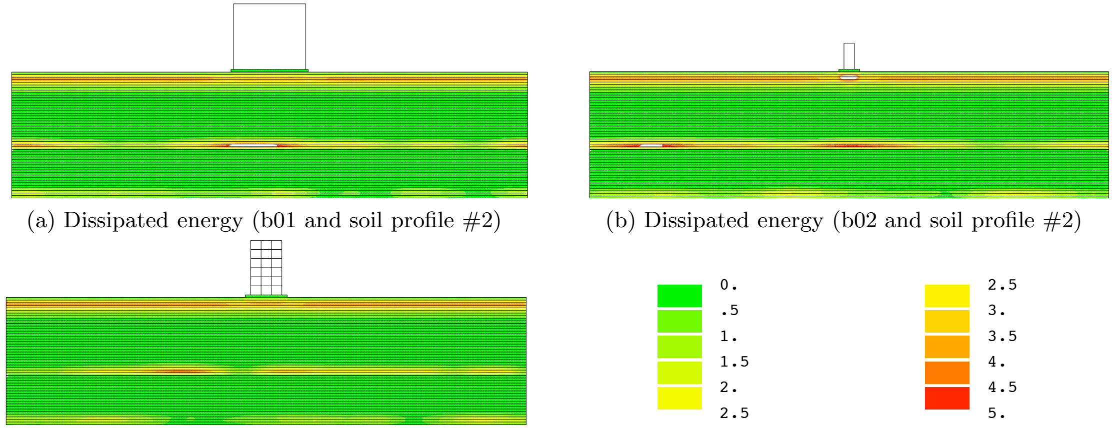
(a) Low-strain shear moduli of the profiles

Confining pressure dependency

An insight of nonlinear soil response



$$I_{soil} = \frac{1}{\Omega}\int_{\Omega}\int_{t} \underline{\underline{\sigma}}(\underline{x}, t) : d\underline{\underline{\epsilon}}(\underline{x}, t) dV$$



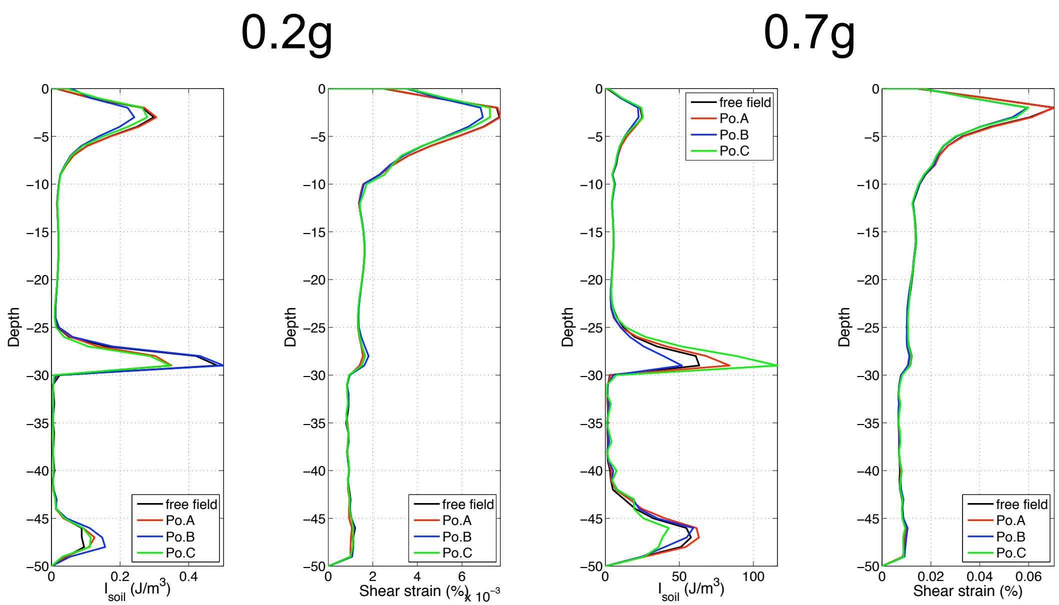
(a) Dissipated energy (b01 and soil profile #2)

(b) Dissipated energy (b02 and soil profile #2)

(c) Dissipated energy (b03 and soil profile #2)

(d) Legend: (J/m^3)

Dissipated energy is higher at interfaces and close to the free surface



(a) Dissipated energy

(b) Maximum shear strain

(c) Dissipated energy

(d) Maximum shear strain

Gandomzadeh (2011)

What do we observe?

- Energy is strongly dissipated at the bottom of each layer and close to the free surface
- Since shear strength increases with depth, the energy is dissipated in the weaker part (transition between layers)
- Furthermore, the impedance contrast increases at each layer interface
- Thus, nonlinear response has a cumulative effect (number of cycles) and competition between impedance contrast (linear part) and material strength (nonlinear part)
- It is therefore necessary to instrument not only the middle of the layers but near their interfaces

Conclusions

Sources of uncertainty (variability) in site response

- Input ground motion (e.g. near- and far-field)
- Low strain properties (linear site response)
- Dynamic soil properties (nonlinear site response)
- Methods of computing site response

What do we need?

- Understanding linear site response
- Inverting earthquake data to obtain dynamical soil properties (up to bedrock?)
- Core sampling and laboratory tests (material strength, granulometry, pore pressure effects, etc.)
- Instrumenting middle of layers and near their interfaces