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

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

identified

Equivalent linear

- the main part of the foreshock record
- the main part of the mainshock record
- just after the main part of the mainshock record

De Martin et al. (2010)

Pioneering work by T. Satoh since the 90’s

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

Mogi et al. (2010)
Inverting for nonlinear soil properties

Assimaki et al. (2010)

Inverting for G/Gmax and damping ratio
An insight of nonlinear soil response

Soil-structure interaction model

(b) Soil profile (#2)

Confining pressure dependency

(a) Low-strain shear moduli of the profiles

Gandomzadeh (2011)
An insight of nonlinear soil response

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

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