Challenge for a better measurement of high frequency seismic motion
(and link with heterogeneity studies)

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Outline

• Importance of the measurement of high frequency for the heterogeneity studies

• Influence of sensor coupling on HF content

• Influence of sensor installation depth on HF content

• Influence of seasonal variations on HF content

• Some evidences of these effects on selected RAP stations

• Does the classical measurement of the “kappa” parameter still make any sense?
Why HF measurements are important to study heterogeneities?

from Shilbe et al. 2018
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Sketches of the different station installation configurations

a. Direct burrial

b. Manhole

c. Shelter

d. Cave

e. Tunnel

f. Vault

g. Borehole

h. Foot of a cliff

i. Gallery covered by blocks
Sketches of the different station installation configurations

a. Burried seismometer (temporary)

b. Accelerometer (permanent)

Seismometer laid on slab (temporary)
Slab soil-structure interaction effects

Soil sites: significant "soil-slab" interaction

Rock sites: small or no "soil-slab" interaction, (same order of magnitude than spatial variability?)

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**Image 1:**

- **a. Horizontal**
  - Graph showing amplification vs. frequency for different sites (e.g., CR1, CS1, CS2, AR, AS).
  - Legend indicating sites: CR1 (Cadarache - Rock site), CS1 (Cadarache - Stiff soil site 1), CS2 (Cadarache - Stiff soil site 2), AR (Argostoli - Rock site), AS (Argostoli - Soft soil site).

- **b. Vertical**
  - Similar graph as Horizontal, showing number of events vs. frequency.

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**Legend:**

- **a. Direct burrial**
  - Image of a direct burial with a depth of ~0.2 m.

- **b. Manhole**
  - Image of a manhole with a depth of ~0.8 m and a width of ~2 m.

- **c. Shelter**
  - Image of a shelter with a depth of ~0.6 m.
Depth effects

a. Horizontal

b. Vertical

Amplification

CR2-3 / CR2-0 (3 m depth / surface)
CR2-45 / CR2-0 (45 m depth / surface)

Number of events

Frequency [Hz]

1 10

Direct burrial

Vault

Borehole

~0.2 m

~3 m

45 m
Depth effects

- **a. Real CR2 $V_s$ profile**
- **b. Homogeneous - $V_s=400$ m/s**
- **c. Homogeneous - $V_s=2000$ m/s**

Diagram showing the relationship between frequency and amplification for different depth conditions.
Depth effects: GRN RAP station

a. H/V

Earthquake H/V ratio

Frequency [Hz]

H/V computed on earthquake records

b. 1D simulation

Amplification

Frequency [Hz]

Site amplification at station (-5 m)

Site amplification at surface

d. Cave

~5 m
Depth effects: NBOR RAP station

i. Gallery covered by blocks

Earthquake H/V ratio

Frequency [Hz]
Depth effects

a. OG35

b. STSM

c. OGMU

Earthquake H/V ratio

Frequency [Hz]

1 10

2 2

3 3

4 4

0.25 0.5

e. Tunnel

h. Foot of a cliff

>10 m

~5 m
Seasonal variations
Seasonal variations

Vs variation seems to be restricted within the very top few meters.
Seasonal variations

a) Velocity profiles (zoom on shallow layers)

b) Velocity profiles (whole)

c) 1D synthetic transfer function: CK0/CK83

Borehole Stations

6m
15m
40m
83m

d) ARGONET data: CK0/CK83

Model dry period
Model wet period
Down-hole
Cross-hole

Model Dry Period
Model Wet Period

Extreme Dry Period
Extreme Wet Period
Effects on ‘kappa’ (slab and depth effects)

a. Measured slab SSI effect at CS1

\[ \Delta \kappa = -26 \text{ ms} \quad \Delta \kappa = +23 \text{ ms} \]

b. Measured depth effect at CR2-45

\[ \Delta \kappa = +35 \text{ ms} \quad \Delta \kappa = +26 \text{ ms} \quad \Delta \kappa = -13 \text{ ms} \]

c. Computed depth effect at GRN

\[ \Delta \kappa = +40 \text{ ms} \quad \Delta \kappa = -26 \text{ ms} \]
Effects on ‘kappa’ (seasonal variation)

a) 1D synthetic transfer function: CK0/CK83

b) ARGONET data: CK0/CK83
Homogeneous site does not exist!

RAP station $V_s$ profiles
1D transfer functions for 20 RAP A-class stations
Effects on ‘kappa’: soil response of rock and hard-rock site

- **‘standard’ rock**
  - Mean $\Delta \kappa = +8$ ms
  - Mean $V_{S30} = 940$ m/s

- **‘hard’ rock**
  - Mean $\Delta \kappa = -8$ ms
  - Mean $V_{S30} = 1420$ m/s
Conclusions

• High frequency in ground motion recordings: crucial for heterogeneity studies

• Slab SSI and depth effects can have a strong impact on HF content of recordings from strong motion (and other) databases

• Seasonal variations can add variability in site response HF measurements

• Measuring kappa without any perturbing effects (SSI, depth, amplification due to shallow weathered layers) could only be done on very, very, very few stations

• The observed statistical difference between ‘standard-rock kappa’ and ‘hard-rock kappa’ is likely due to local amplification (and not due to attenuation differences)