

PRENOLIN Project

An international benchmark on numerical simulation of 1-D nonlinear site effect. Verification phase on idealistic cases and validation on real sites

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² Kyoto University

³ ISTERre, Grenoble

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⁵ CEA, Cadarache

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Outline

- 1- Presentation of the project goals and organization
- 2- Verification phase
- 3- Validation phase
- 4- Conclusions and perspectives

1- Background and motivation

Accounting for local conditions in hazard assessment for nuclear facilities – France "Special sites" : heavy expectations on numerical approach

Previous Verification / validation exercises

- ESG1992 : Parkfield Turkey Flat + Ashigara Valley
 - Blind exercises - variable SHAKE results...
- (ESG1998 Kobe : source + site, not blind)
- SCEC : Los Angeles area, 3DL (LF + BB)
- ESG2006 : Grenoble, 2DL/3DL
- Turkey Flat, NL post Parkfield 2004
- E2VP : Volvi/Euroseistest, 3DL + 2DNL (+2DL)
- VELACS : Liquefaction (centrifuge)
- ...

Sites not totally 1D
Difficulties with
deconvolution of
outcrop motion

2-D too complicated to
analyze NL soil model
implementation

Lessons for Prenolin

Be less ambitious / more humble

reach good results within a limited amount of time (2 years)

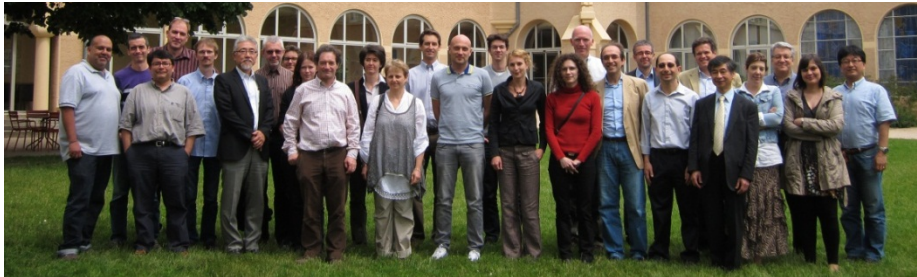
Check NL models on 1D soil columns

- On simple sites with unambiguous data and models
 - With strong motion data (vertical arrays)
 - With well-controlled lab tests / soil parameters
 - As close as possible to 1D sites
- Our *a priori* choice
 - Simple 1D "Canonical" models
 - Carefully selected KiK-net sites

Expected outcome

- Verification and validation of NL codes in simple conditions
 - 1D, no liquefaction, simple shear stress analyses
 - Real and canonical sites
- Assessment of epistemic uncertainties
- Guidelines for using deterministic, physics-based, NL simulation in (D+P) SHA
 - Required geotechnical / geophysical measurements
 - Quality criteria and control for NL computations
 - Corresponding budgets and feasibility

The participants



USA:

- UCSD, California,
- UW, Washington,
- UC Davis, California,
- GATECH, Georgia,
- CEEI, Illinois

France:

- ISTERre, Grenoble
- IFSTTAR, Marne la Vallée
- CETE, Nice
- CEA, Cadarache
- EdF, Aix en Provence
- BRGM, Orléans
- CETE, Nice
- IRSN, Fontenay aux Roses
- EdF, Clamart
- ECP, Paris

Switzerland :

- ETHZ, Zürich

Italy:

- Univ. Bologna
- Univ. Roma
- Polito, Torino

Greece:

- AUTH, Thessaloniki
- NTUA, Athens

Japan:

- DPRI, Kyoto
- DPRI, Kyoto

Slovakia:

- UNIBA, Bratislava

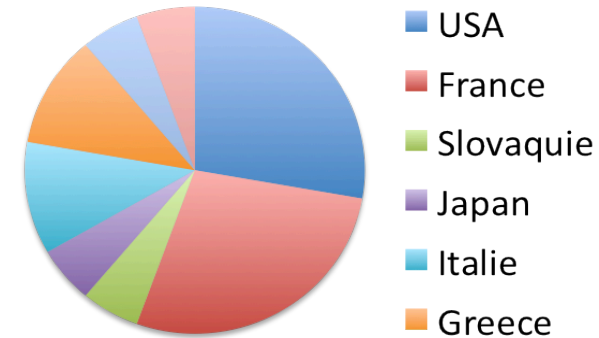
Equipes de modélisation
Co-organisateurs

Some additional information

Overview teams and codes

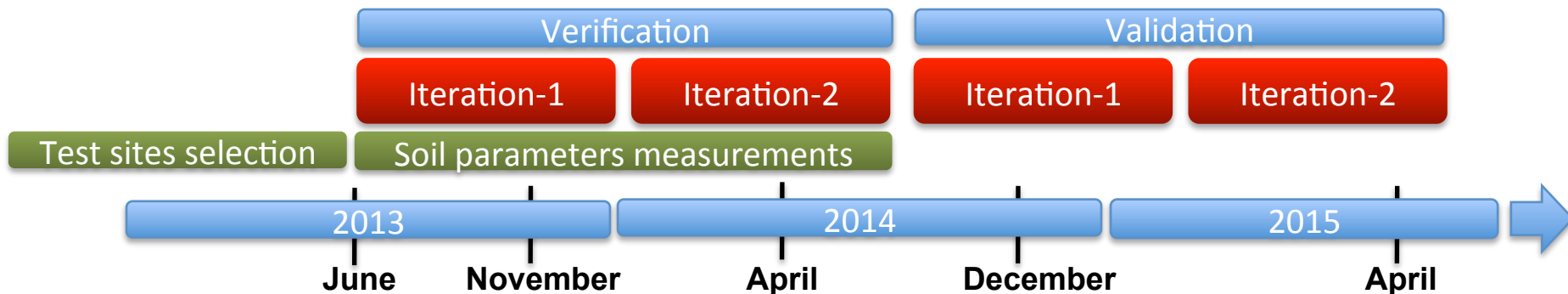
21 Participant teams / **26 Codes tested**

Same codes tested by different teams
Some share similar nonlinear models



- Variability inter- nonlinear models
- Variability inter- Numerical method (with same nonlinear model)
- Variability inter-Users (same codes)

Road map



Numerical codes and team appellation

- SeismoSoil (A-0),
- FLIP (B-0),
- PSNL (C-0),
- CYBERQUAKE (D-0),
- NOAH-2D (E-0),
- DEEPSOIL (J-0 EQL and J-1, F-0 and M-2,)
- NL-DYAS (G-0),
- OPENSEES (H-0),
- 1DFD-NL-IM (K-0),
- ICFEP (L-1),
- FLAC.7.00 (M-0),
- DMOD2000 (M-1),
- GEFDYN (N-0),
- EPISPEC1D (Q-0),
- real ESSI (R-0),
- ASTER (S-0),
- SCOSSA-1,2 (T-0),
- SWAP-3C (U-0),
- GDNL (Y-0),
- SANISAND (W-0),
- EERA (Z-0)
- PLAXIS (Z-1).

Different code implementation

Discret. scheme:

- (i) **finite-element** (B-0, C-0, D-0, F-0, H-0, J-0, L-1, M-0, M-2, N-0, Q-0, R-0, S-0, T-0, U-0, Y-0 and Z-1),
- (ii) **finite-difference** (A-0, E-0, G-0 and K-0).

Backbone curve

- (i) **Ial's model** (B-0, E-0, Q-0)
- (ii) **Iwan's model** (K-0, L-1, U-0, Y-0),
- (iii) **Phillips and Hashash's model** (F-0, J-0, M-2, T-0),
- (iv) **all other models.**

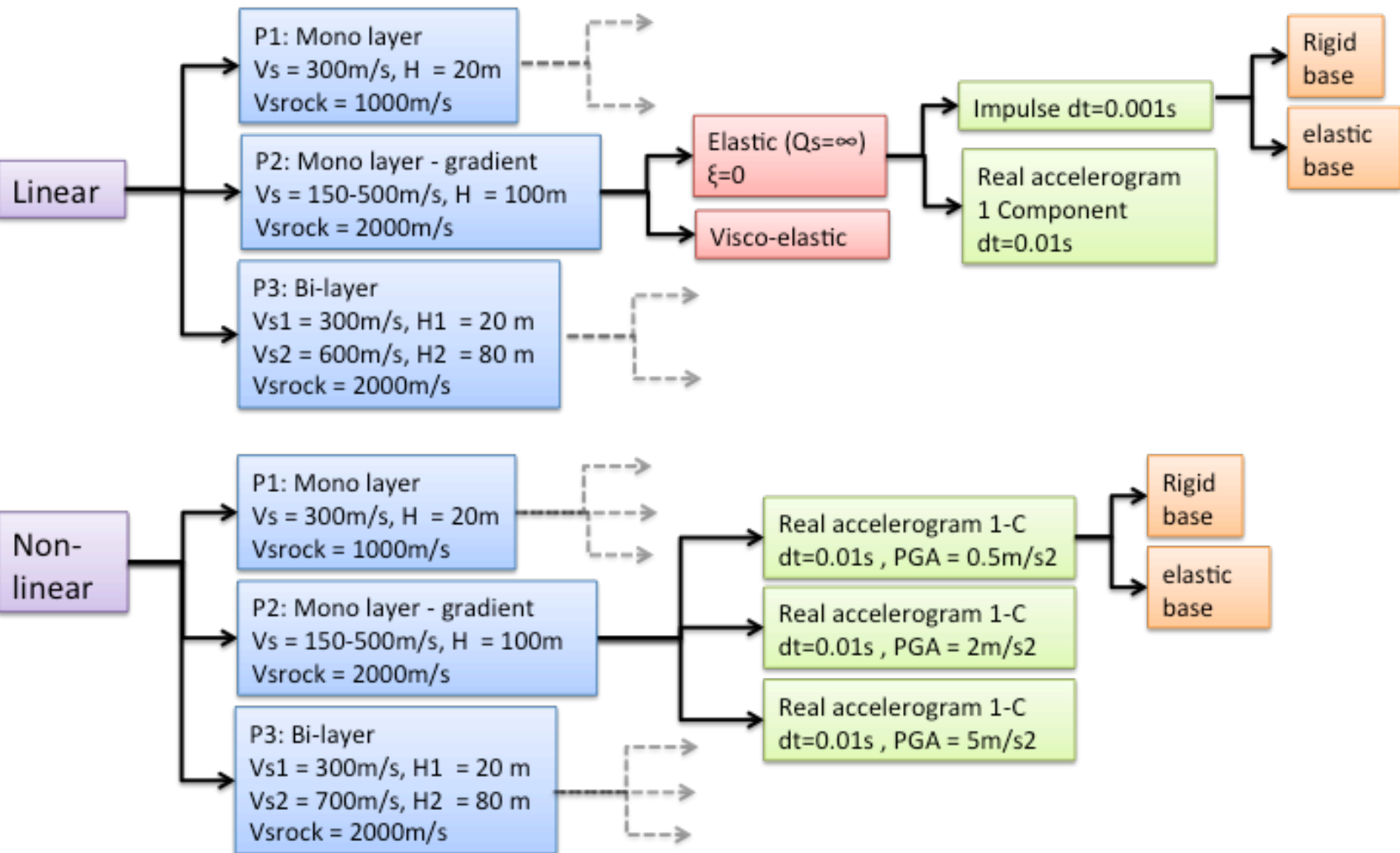
linear att. Imp.

- (i) **frequency-independent attenuation** (A-0, E-0, F-0, J-0, J-1, K-0, M-2, Q-0 and Z-0),
- (ii) **Rayleigh damping** (B-0, G-0, H-0, L-1, M-0, R-0, S-0, T-0, Y-0 and Z-1),
- (iii) **low strain hysteretic damping** (C-0, N-0, D-0 and R-0).

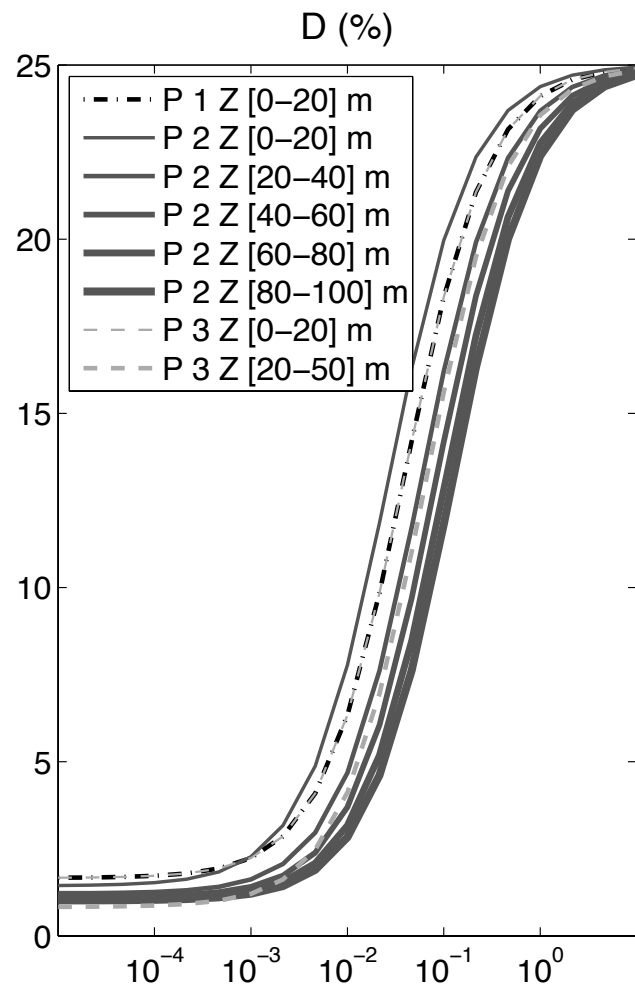
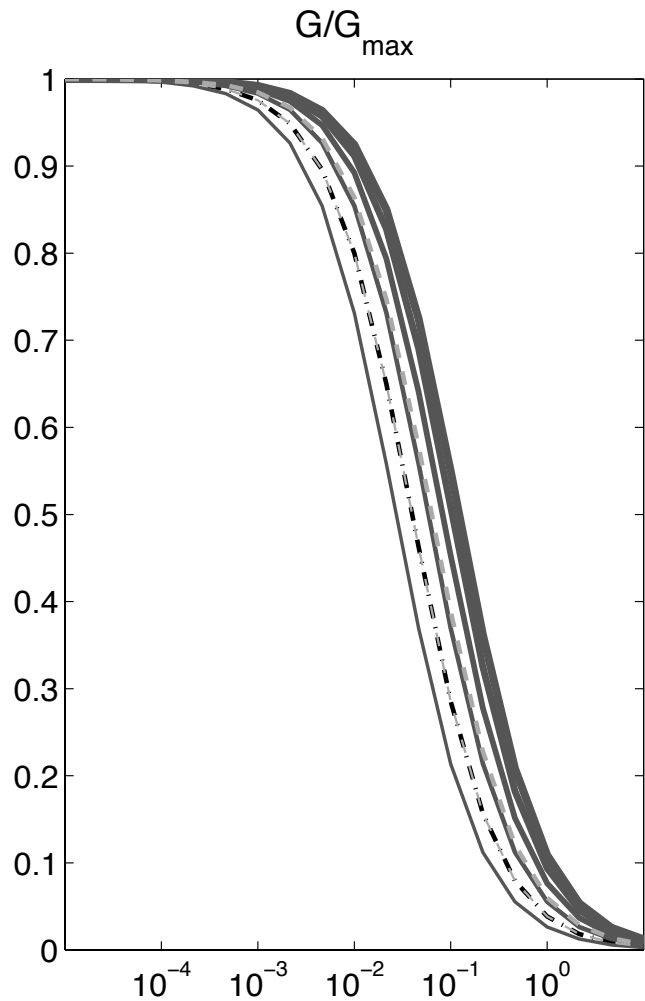
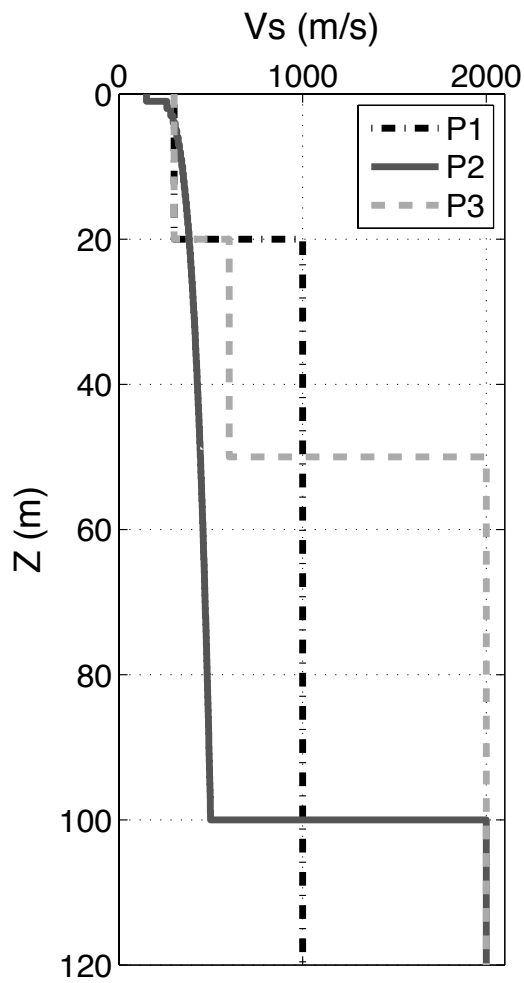
Loading/unloading

- (i) **No masing** (A-0, B-0, E-0, J-0),
- (ii) **Masing rule** (all other teams).

Idealistic cases



Idealistic cases: soil parameters



What did we ask for?

- **Acceleration THs $a(t, z_i)$, $\Delta t = 0.01s$**

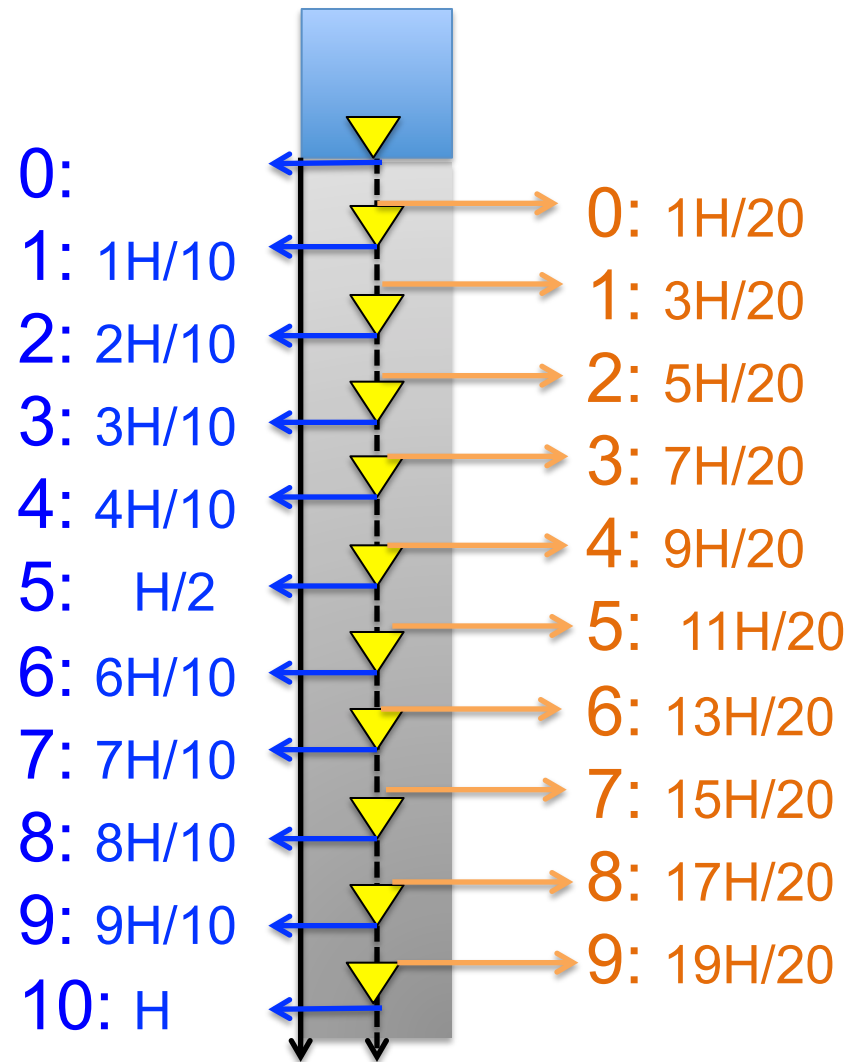
- ✓ $Z_1 = 0$
- ✓ $Z_n = H$
- ✓ $\Delta z = H/10$

- **Strains $\gamma(t, z_i)$**

- **Stresses $\tau(t, z_i)$**

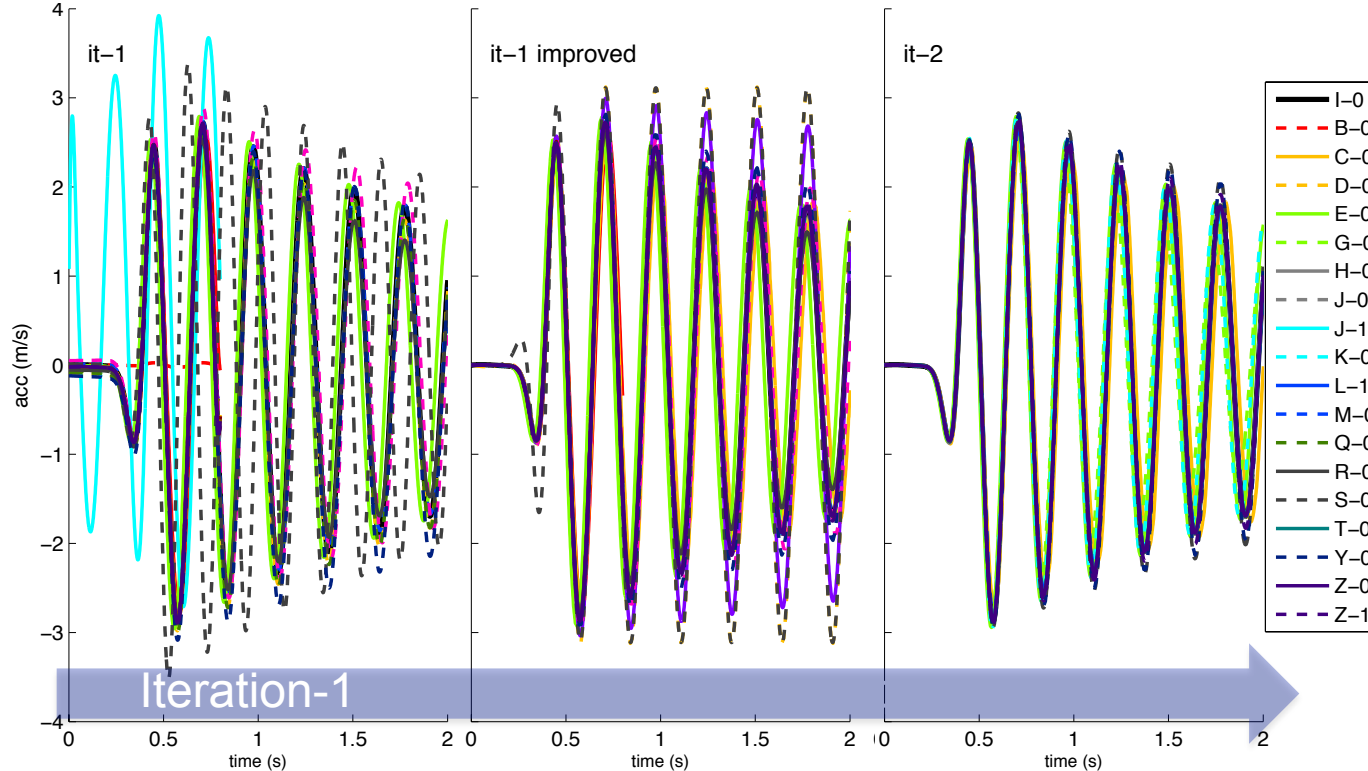
- ✓ $Z_1 = H/20$
- ✓ $Z_n = 19H/20$
- ✓ $\Delta z = H/10$

- **G/Gmax degradation and damping curves per soil layer**



Results: Linear elastic and visco-elastic cases

Acceleration: Ricker Pulse GL-0



Profile: P1

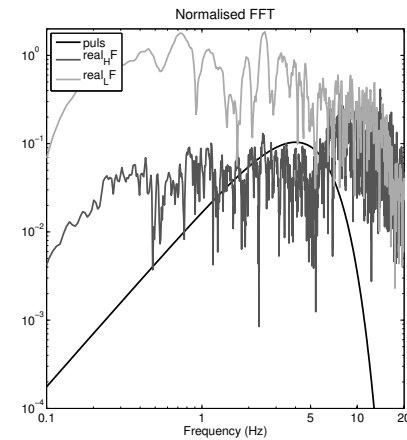
Computation: **Visco-elastic**

Condition sub: **Rigid**

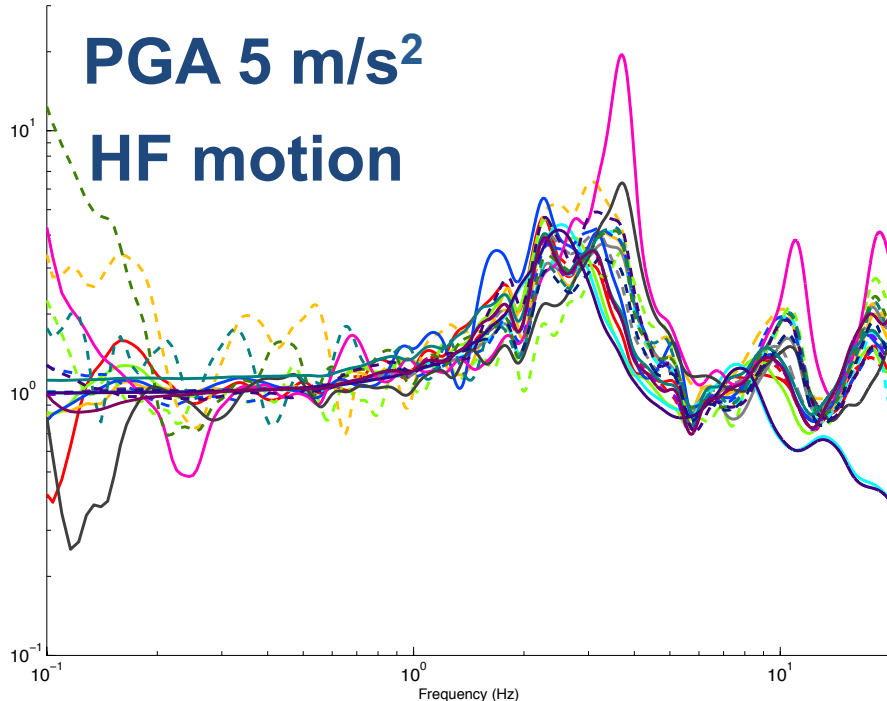
- From it-1 to it-2: Convergence almost achieved !
- Most of the divergences came from minor mistakes
 - Pb in units,
 - Pb of numerical dispersion
 - Pb of damping calibration (still to be done!)
 - Pb in input motion consideration and soil properties

Results: nonlinear computations

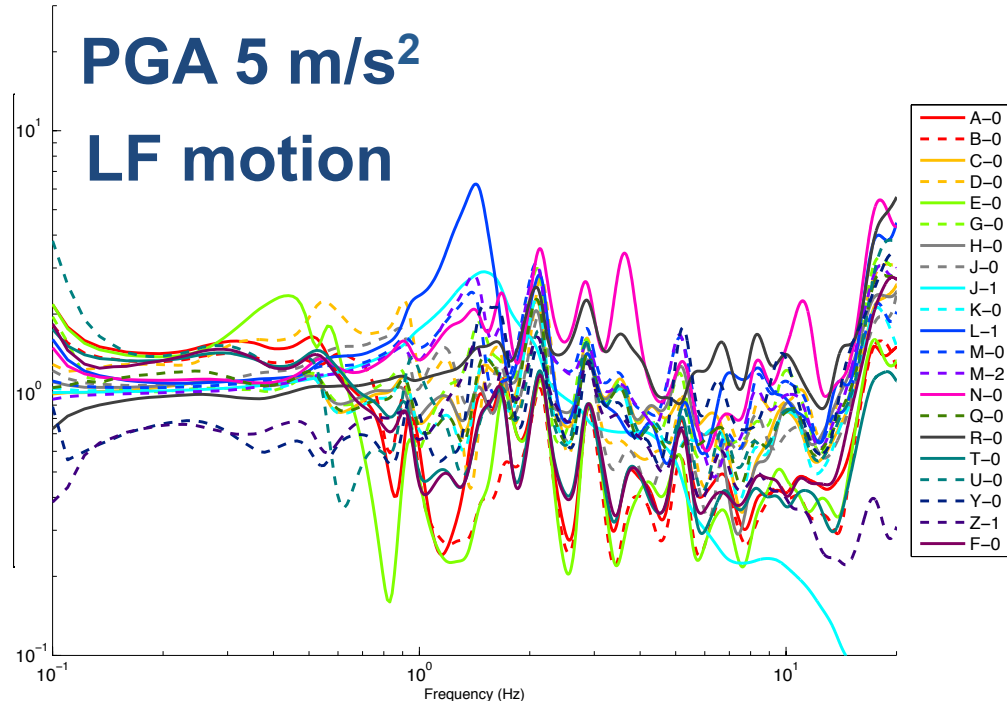
Variability and reference motion frequency content



TF (surf/ref) P: 1 Computation: NL Input: real-3-HF CL: R



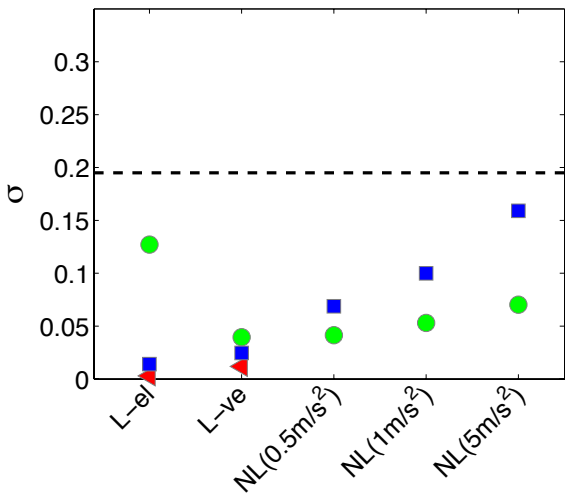
TF (surf/ref) P: 1 Computation: NL Input: real-3-LF CL: R



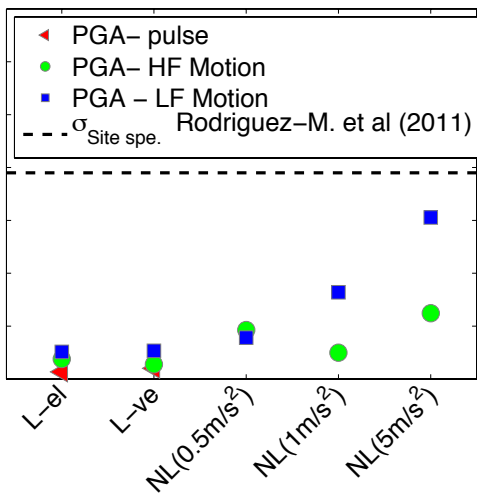
What is the effect of the frequency content of the input?

Epistemic uncertainty: example P1

R Sub.



E Sub.



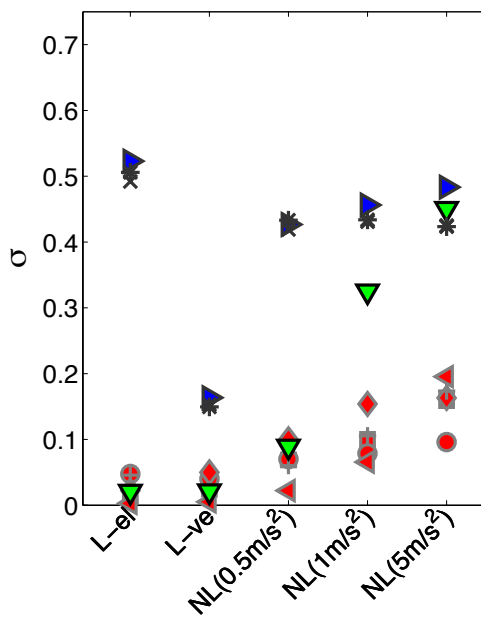
Standard deviation PGA

- Increase with PGA level
- Greater for LF motion
- Below single sigma station

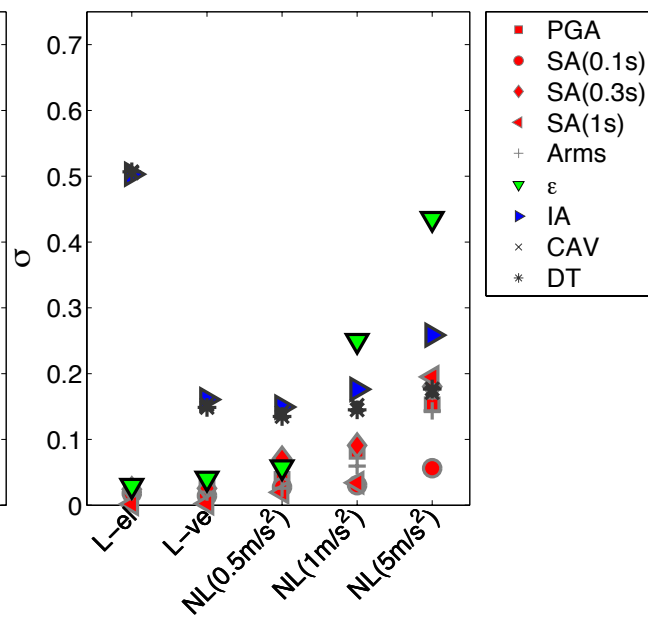
Standard deviation intensity parameters:

- R/E sub: Greater for duration based parameters (IA CAV DT) compare to peak values (PGA, SA, A_{rms})

R sub.



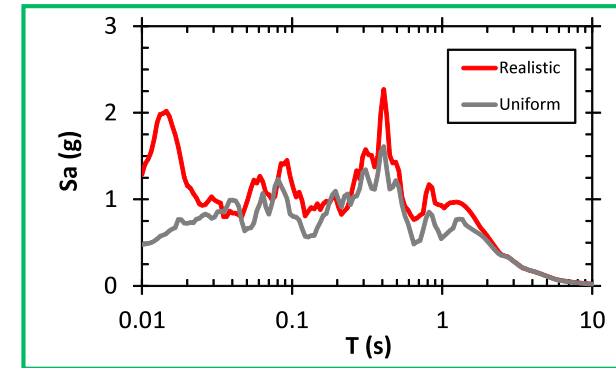
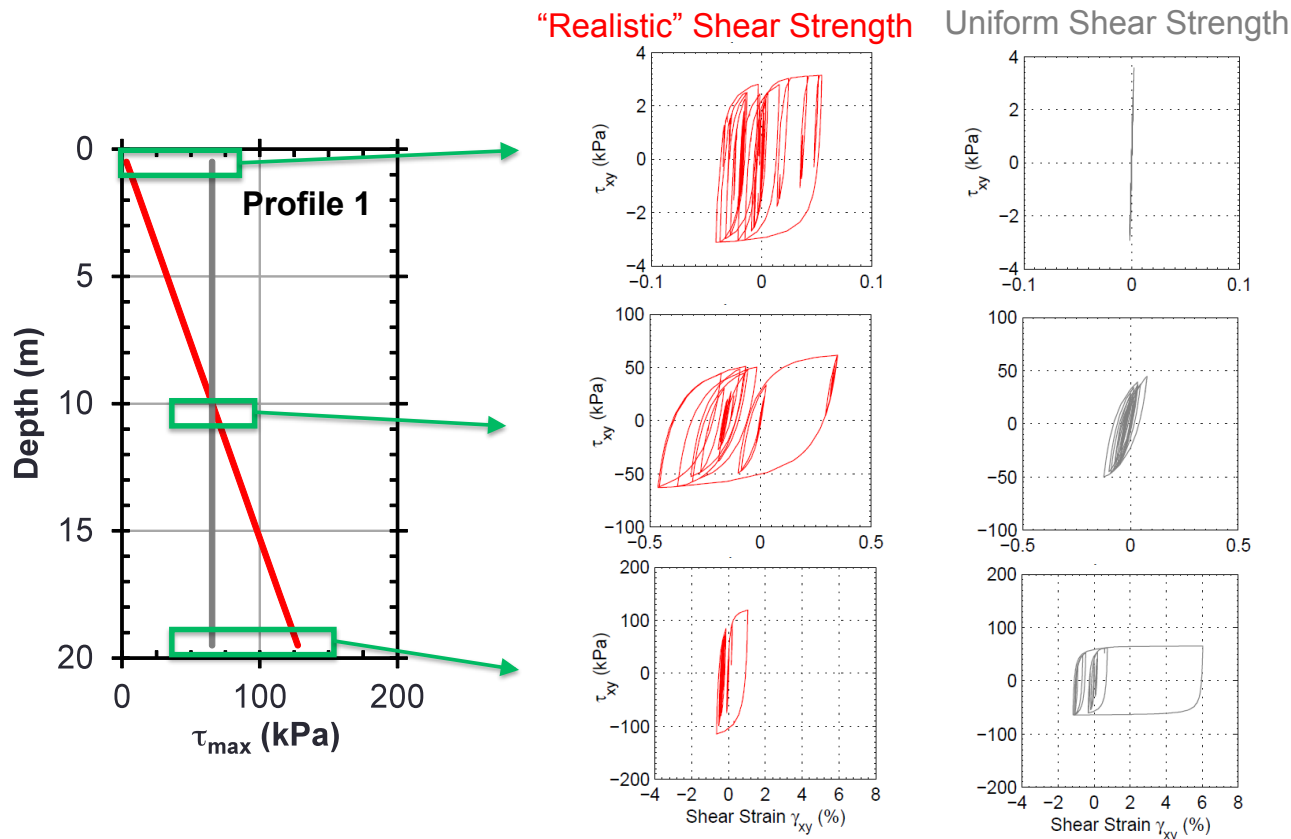
E sub.



Results: nonlinear computations

Can we reduce the epistemic uncertainty?

- ✓ Still some issues of interpretation : Strength profile, large effect on results



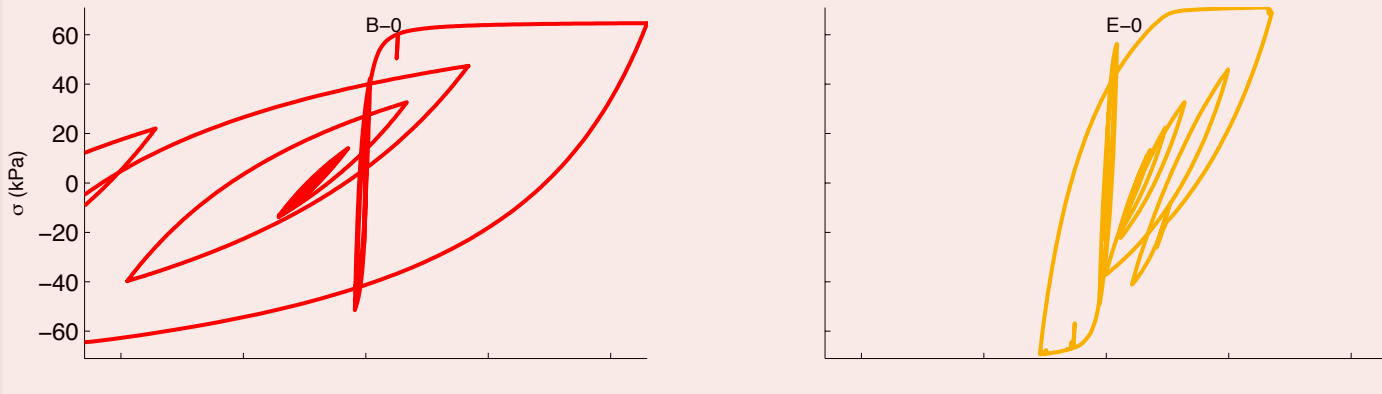
J.Gingery, 2014

Results: nonlinear computations

Can we reduce the epistemic uncertainty?

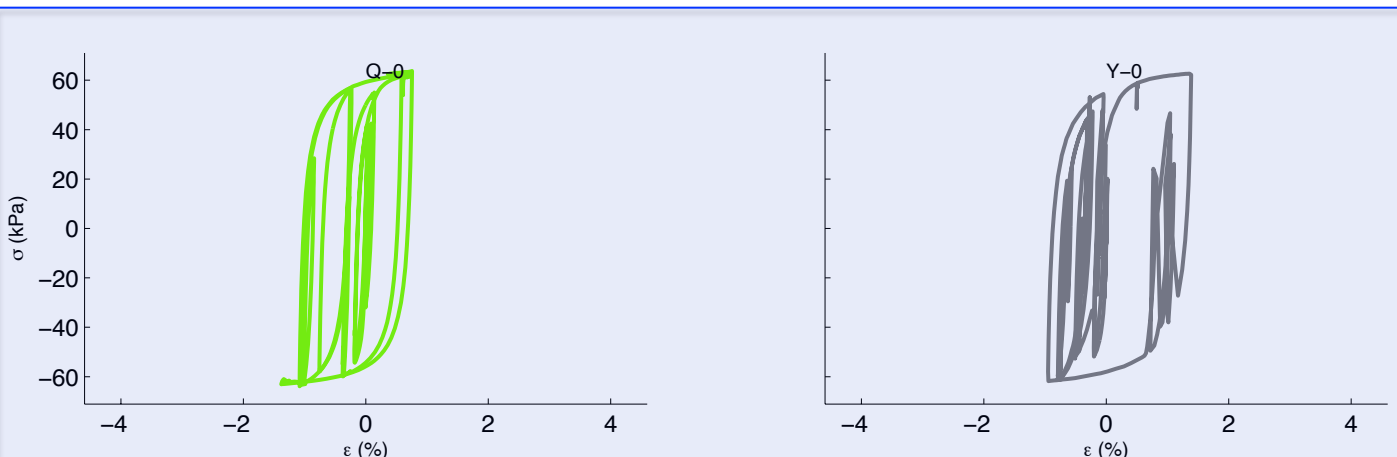
- ✓ Still some issues of interpretation : Strength profile, large effect on results
- ✓ Effect of the damping control: stress-strain curves \neq codes same NL models

Stress-strain P: 1 Computation: NL Input: real-3-LF CL:



Damping control

Z=20m



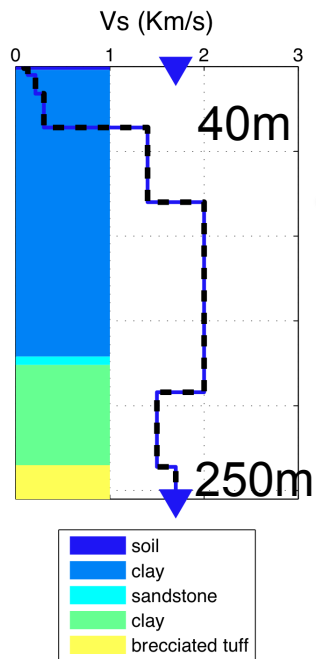
No Damping control

Site selection for VALIDATION phase

criteria

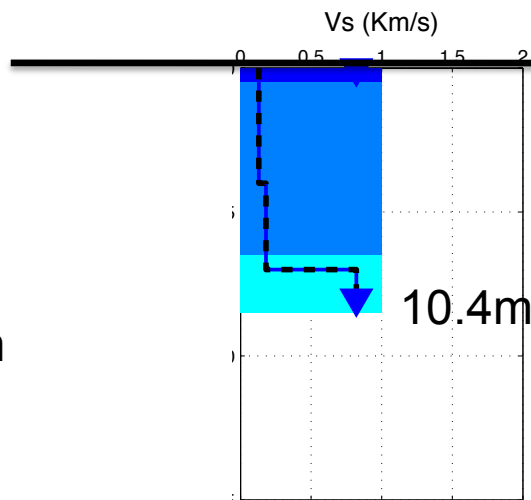
- 1- Sites with 1-D configuration
- 2- Sites having recorded weak and strong motion
- 3- Sites with non-linear soil behaviour (Cyclic mobility or not)

KSRH10: Kiknet site

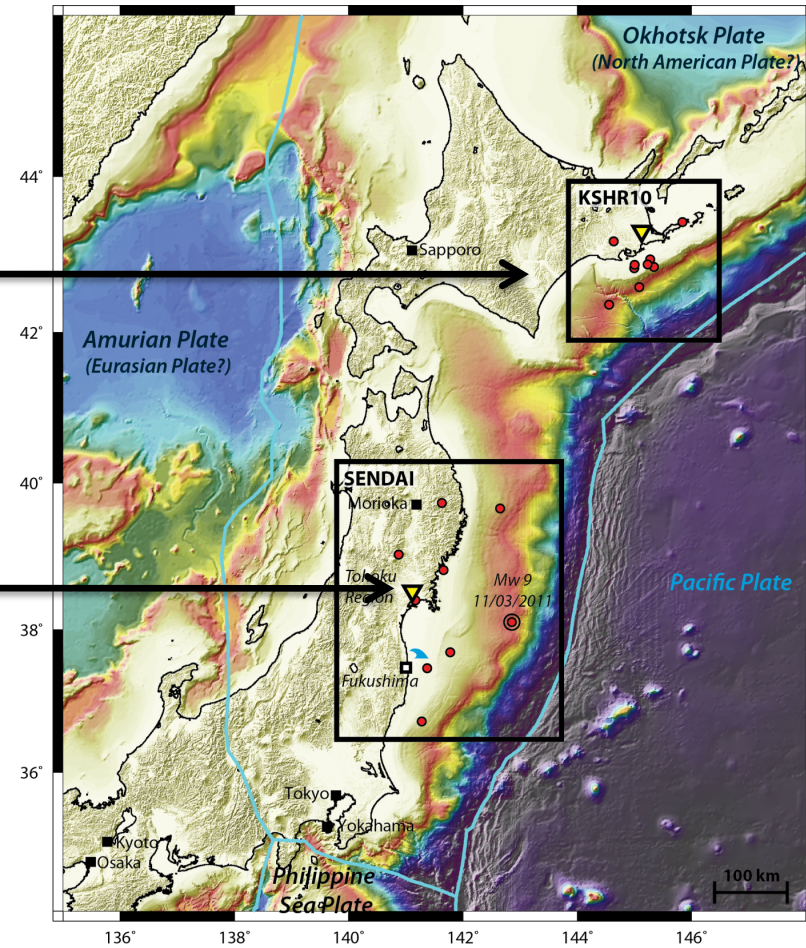


Deep site

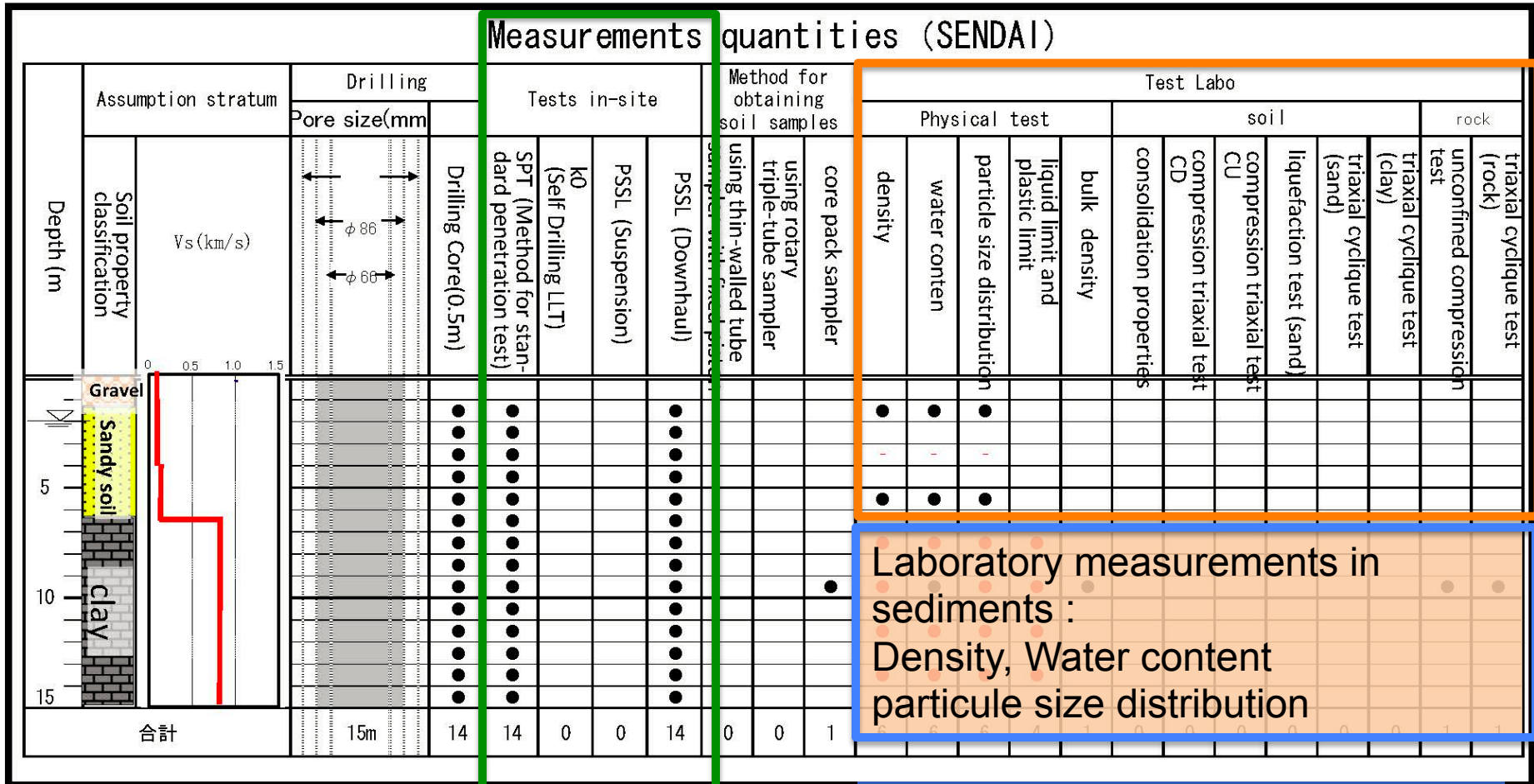
Sendai: PARI site



Shallow site



Site characterization: Example Sendai



+ multiple MASW lines

N-SPT

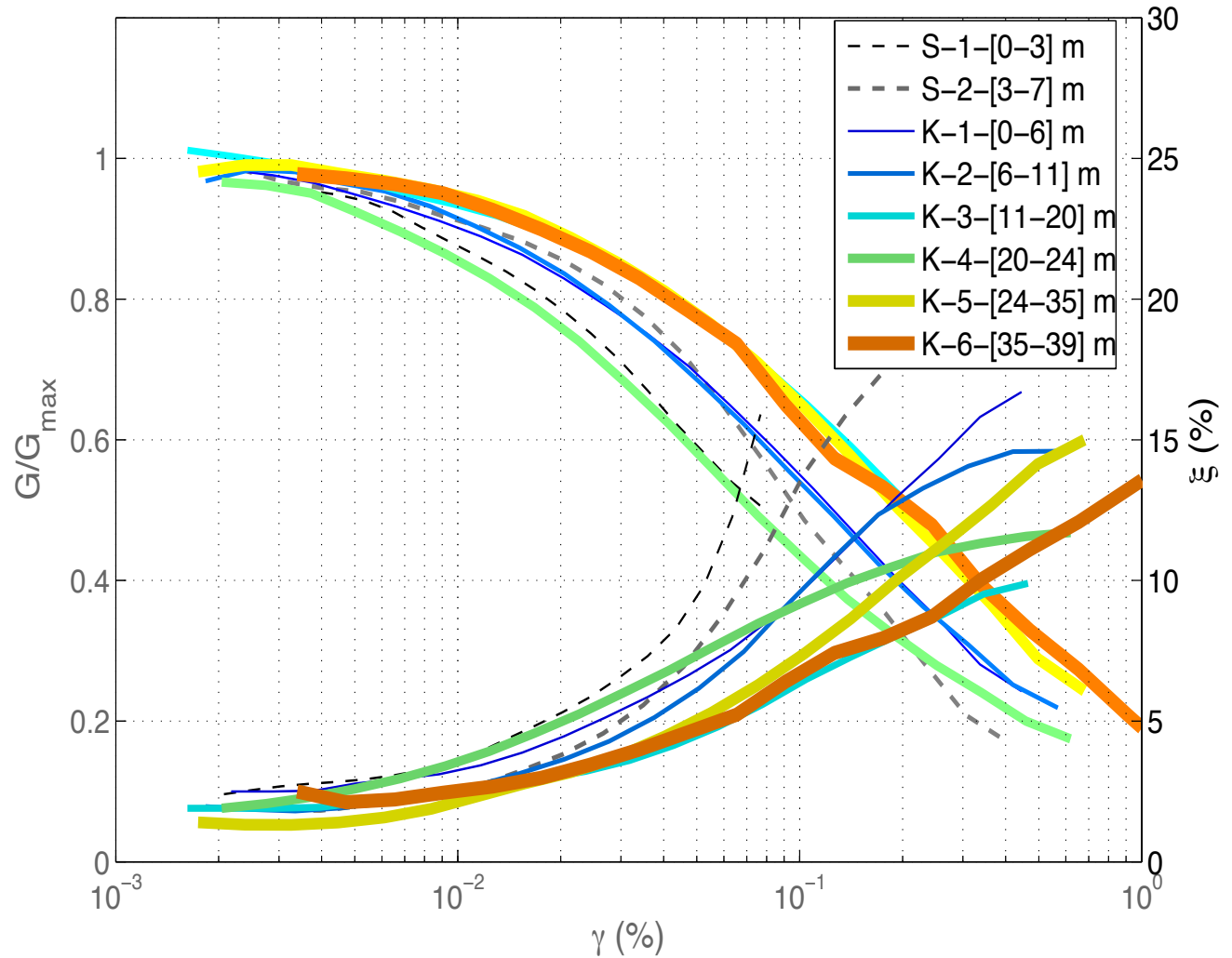
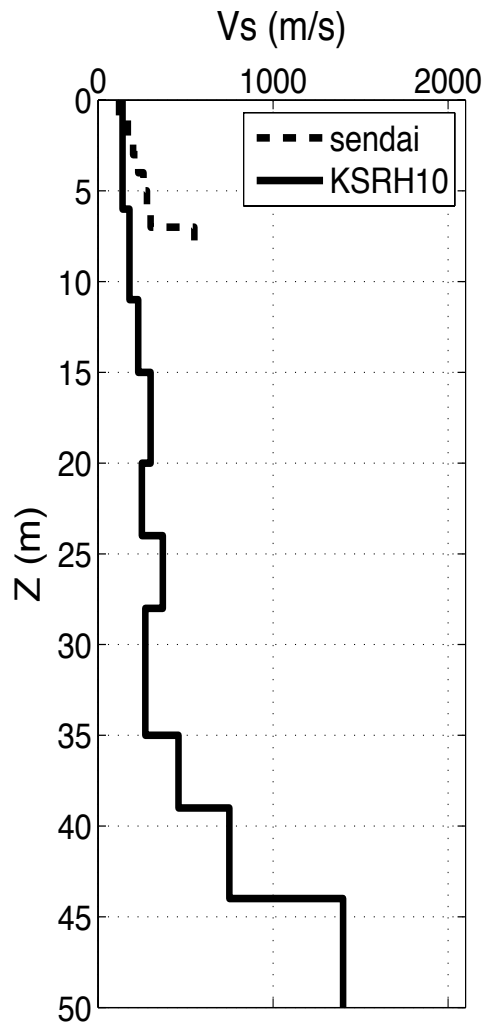
Vs

Laboratory measurements in sediments :
 Density, Water content
 particule size distribution

Laboratory measurements at rock:

- Bulk density
- Unconfined compressional test
- Triaxial cyclic test

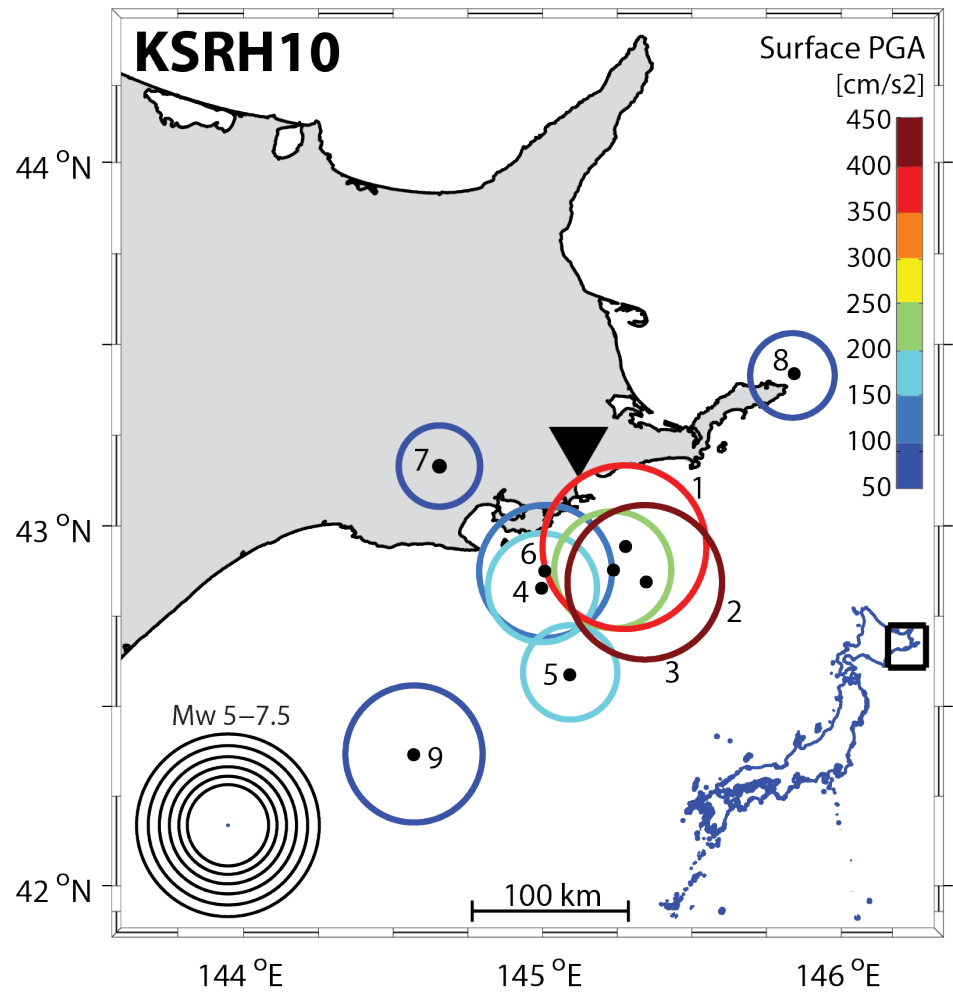
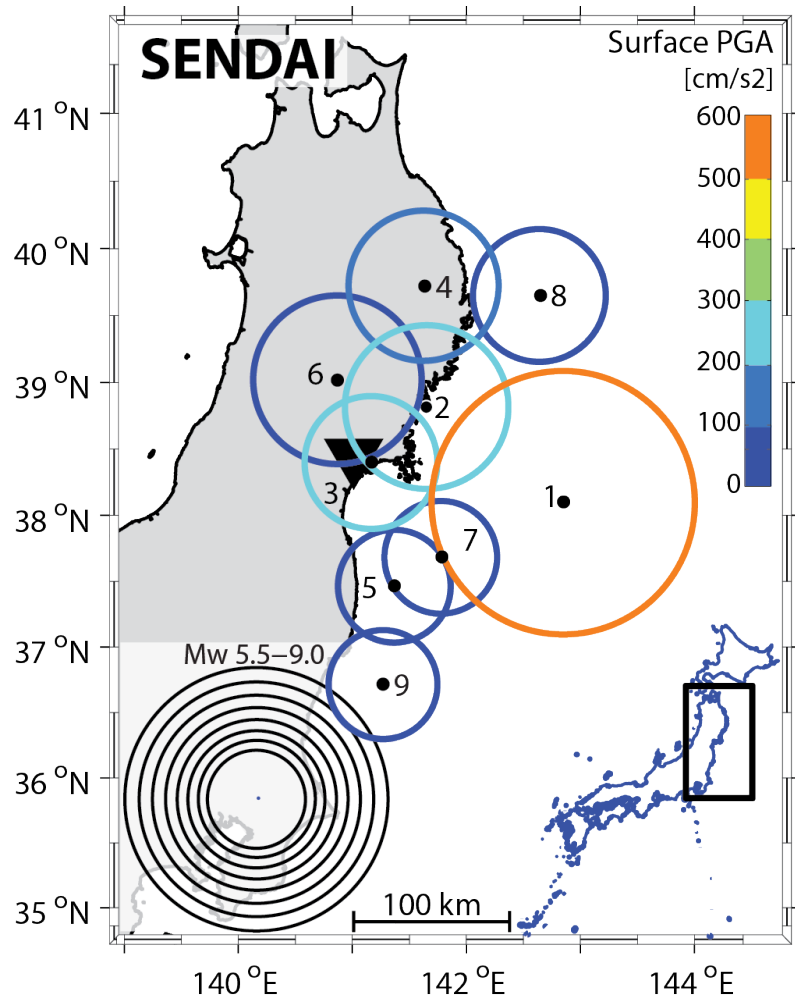
Soil parameters for the simulations



Input motion used

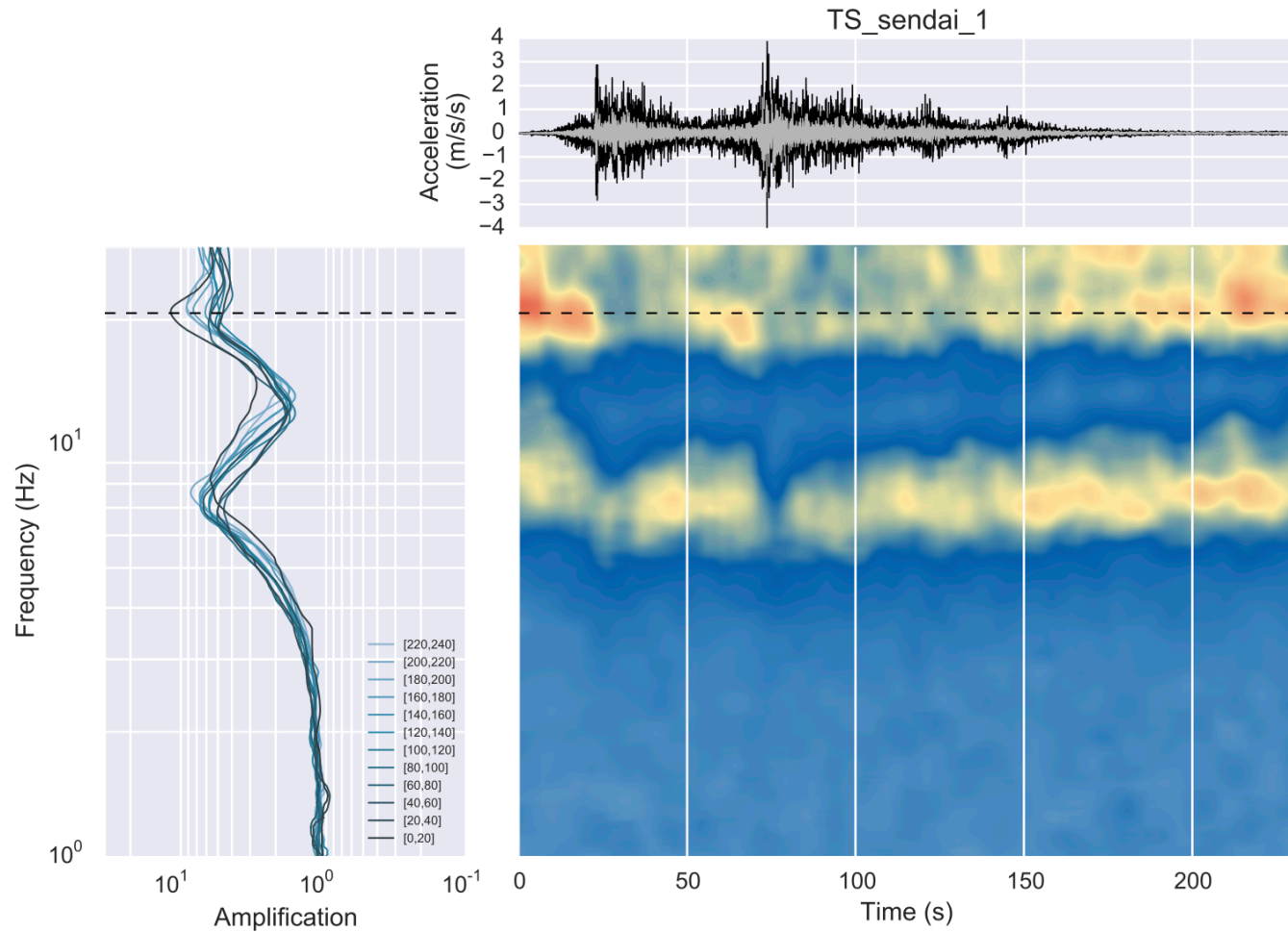
9 input motions for each site : 3 PGA levels x 3 freq. Contents:

- **Sendai** PGA surf. From 10 to 400 cm/s^2
- **KSRH10** PGA surf. From 60 to 440 cm/s^2



Time-dependent spectral ratio

INPUT 1 Observation

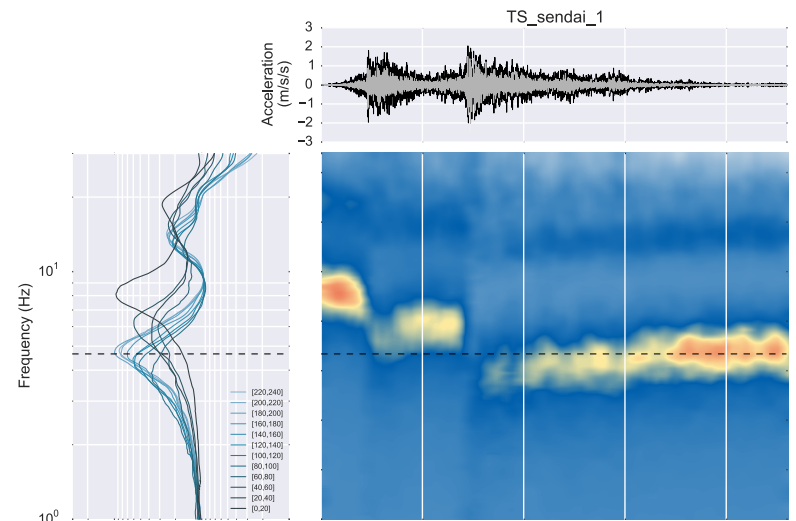
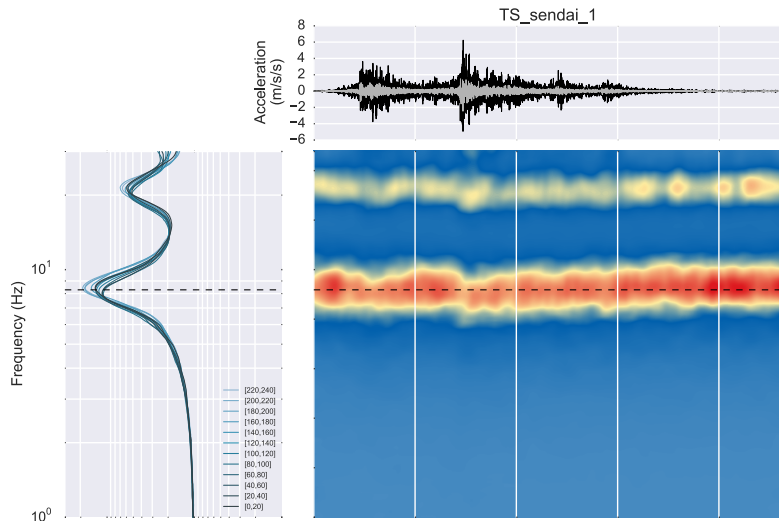


Time-dependent spectral ratio

A-0

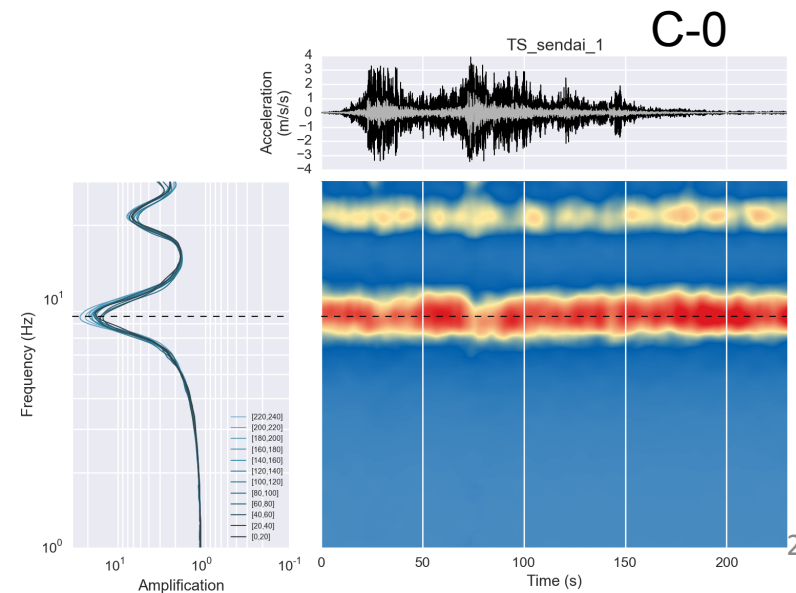
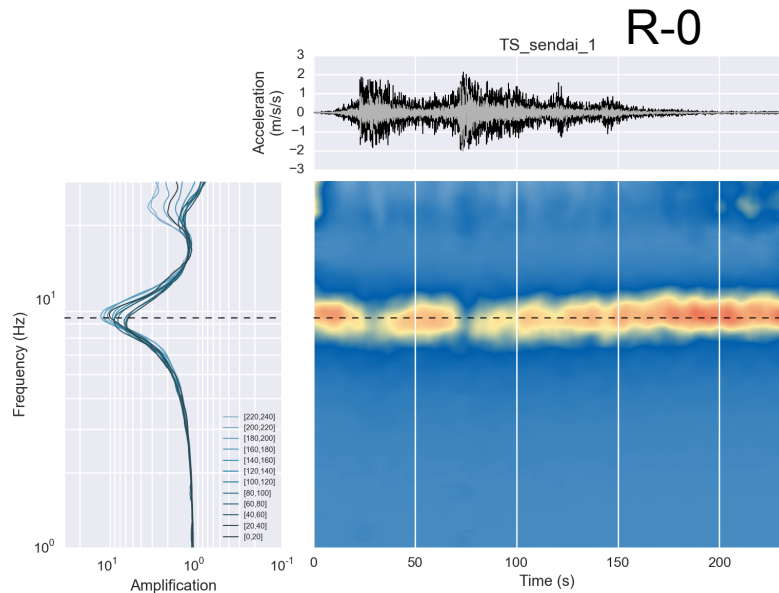
B-0

INPUT 1 Computations



R-0

C-0



Validation phase Iteration 1

Main Conclusions (relative to empirical observations):

- Systematically **over-estimated** simulated **transfer functions**
- Systematically **under-estimated effects** of simulated **non-linear behavior**

Possible explanations of result variability:

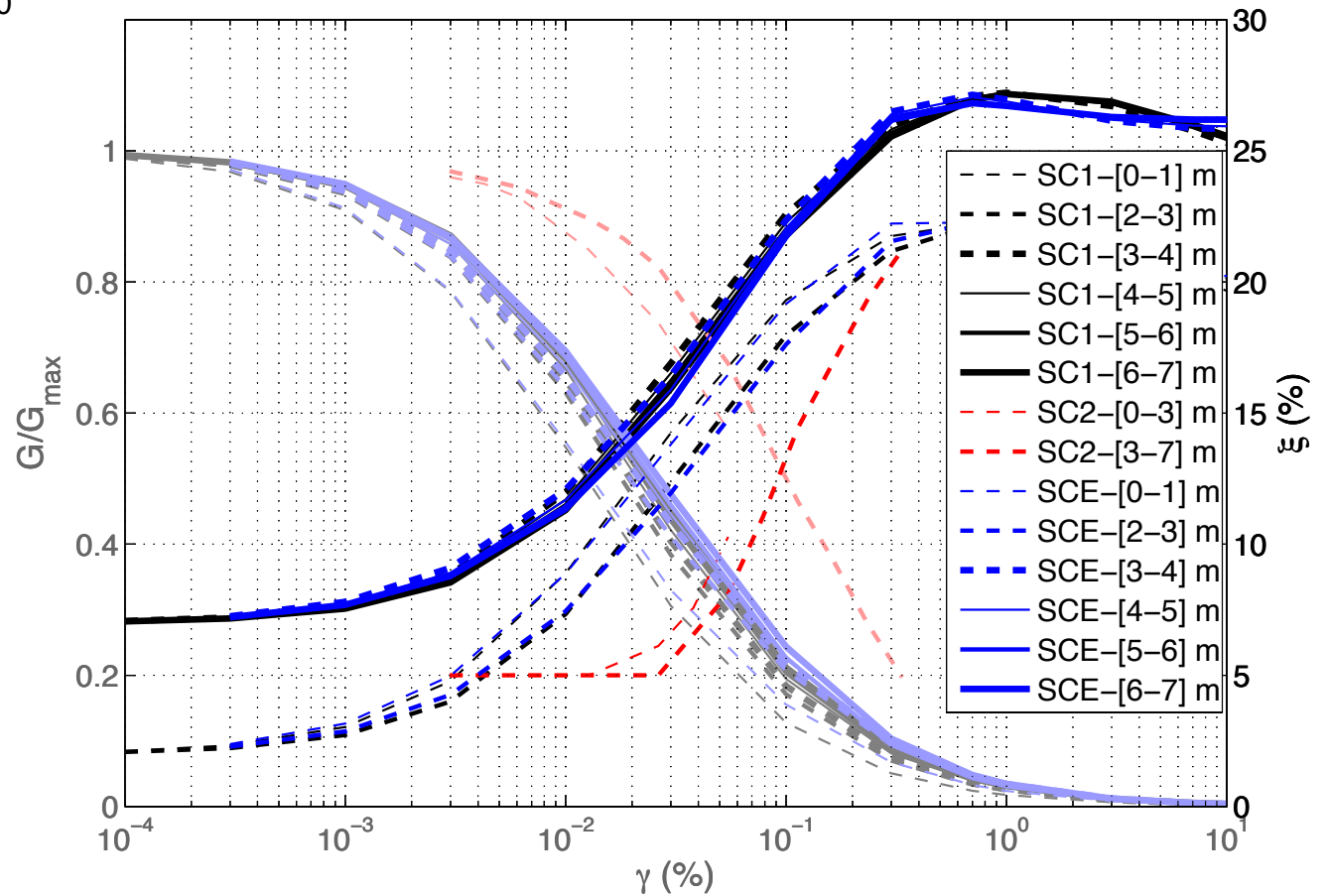
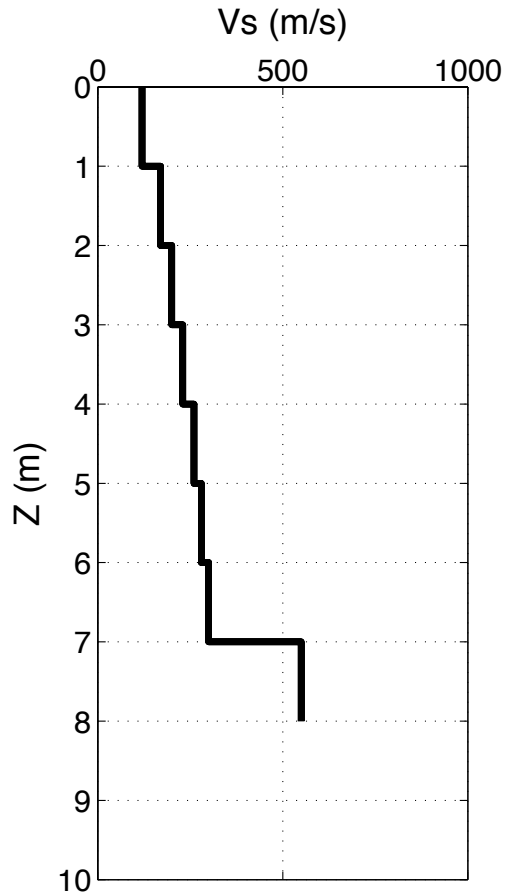
- * * Uncertain or inadequate soil parameters
- * Non-vertically incident plane S waves
- * Component-to-component coupling not accounted for in 1D, single component computations
- * Non-1D soil conditions (2D or 3D)

(**) Definition of a new soil column from GT5 and maybe some other teams (S-0...)

(*) Points which were verified in an internal report « *PRENOLIN: Description of the input motions used in the Validation phase* » and whose results form the basis of the requested new calculations

New calculations to be performed

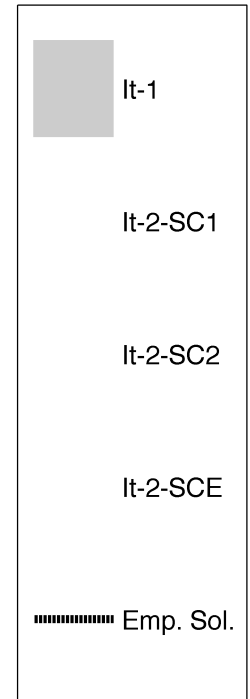
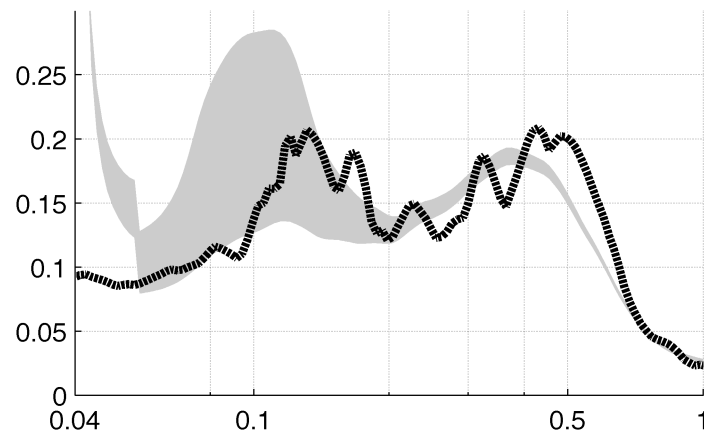
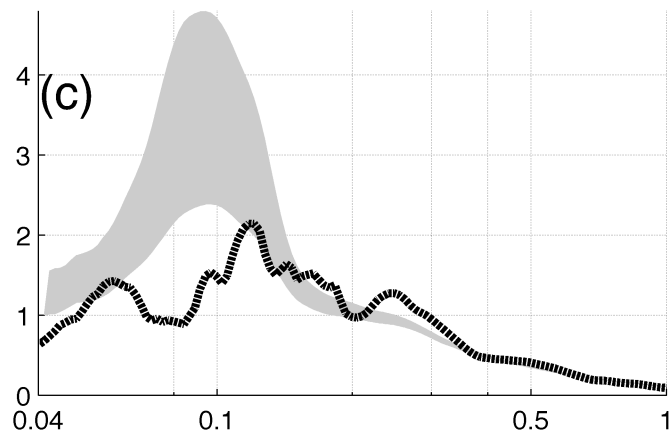
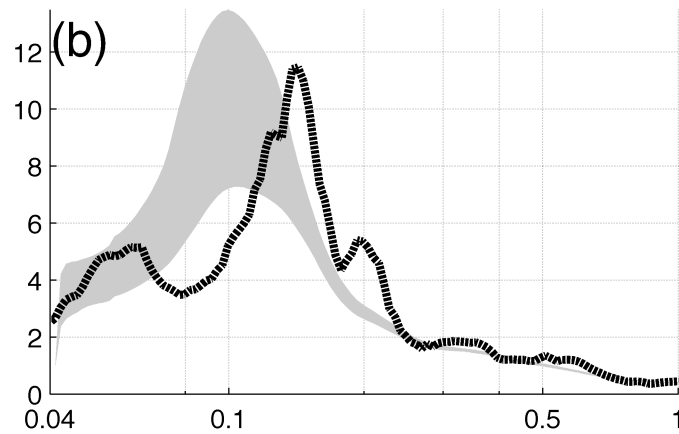
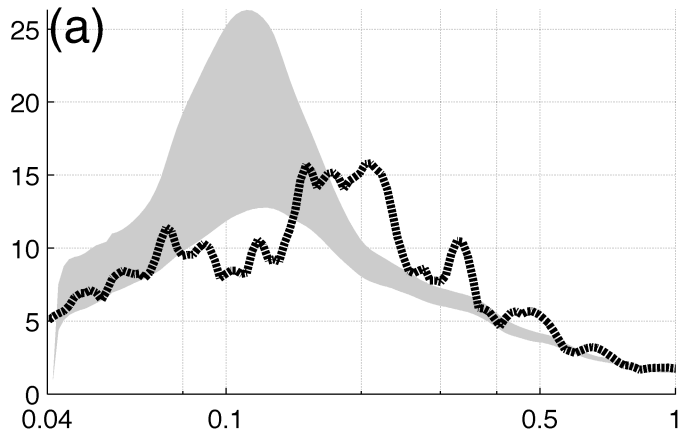
Imposed and preferred models



Team J did effective stress analysis

Envelope of the results

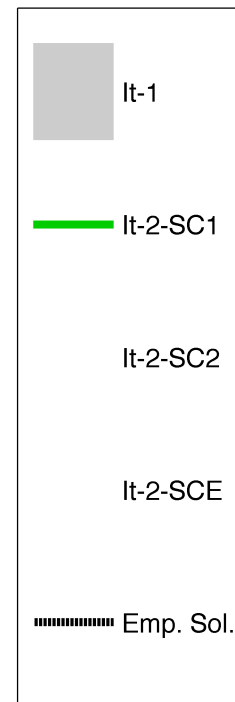
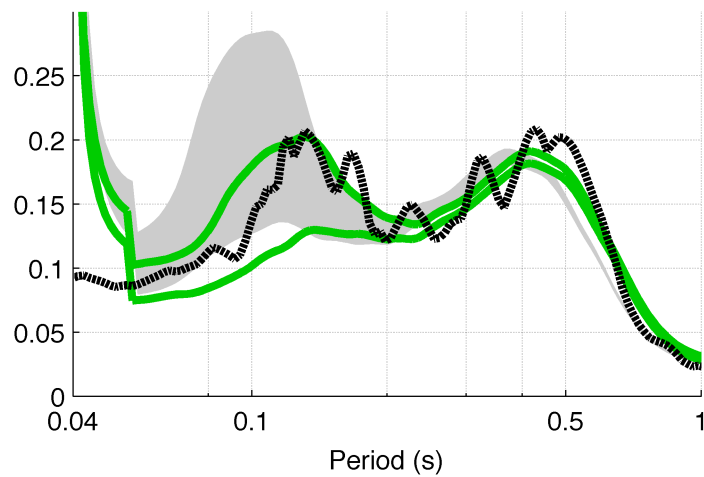
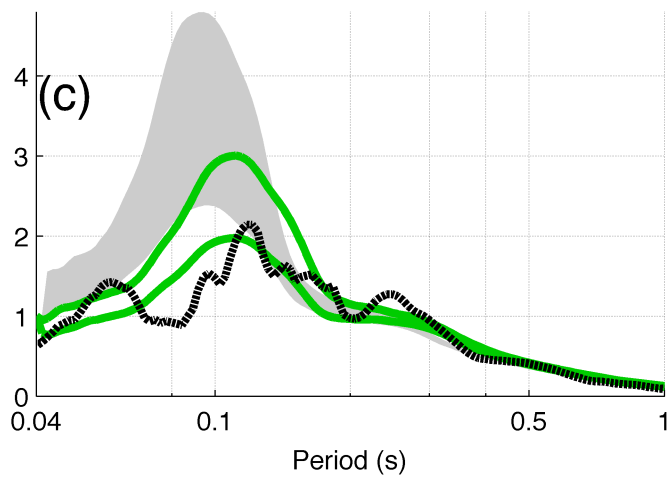
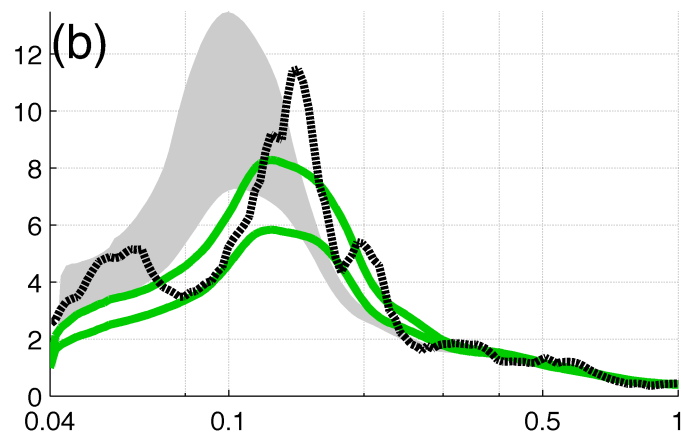
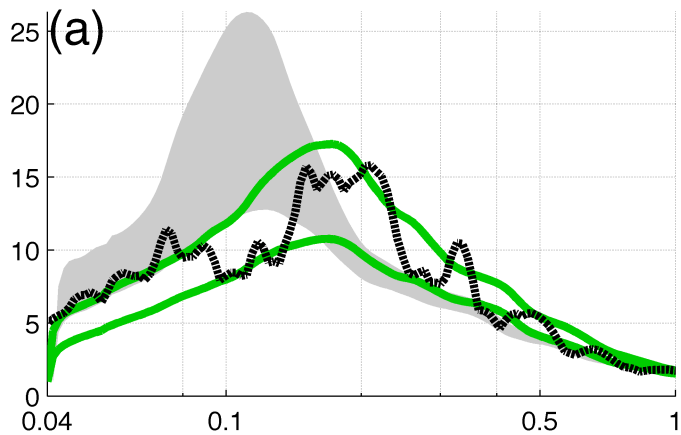
SA



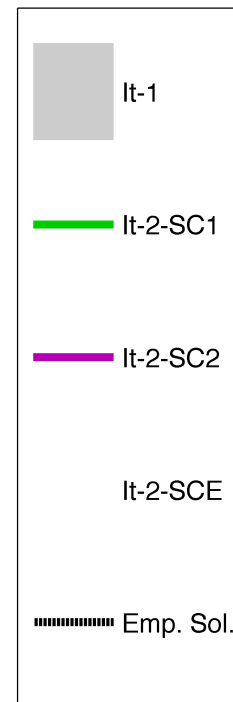
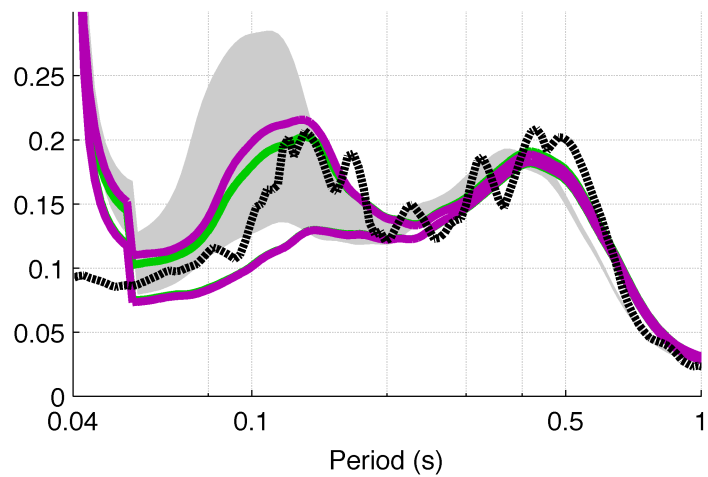
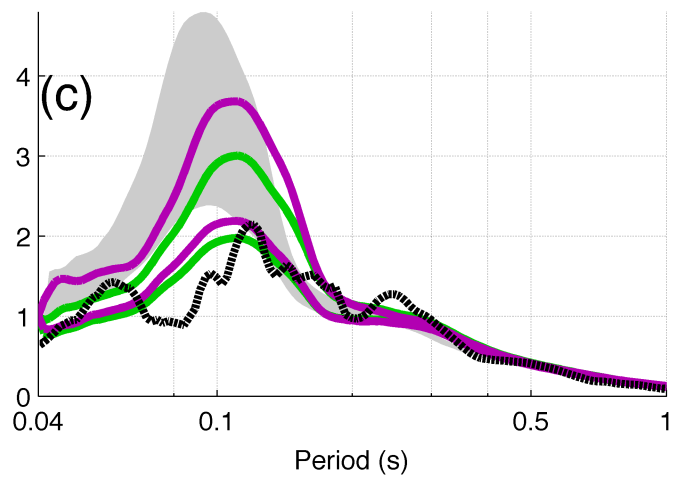
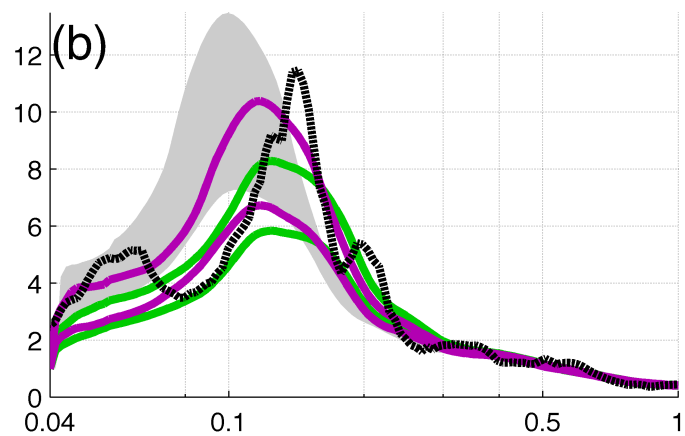
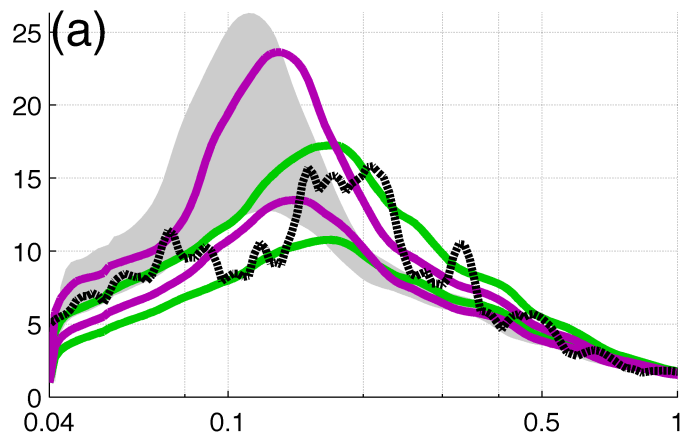
Period (s)

Period (s)

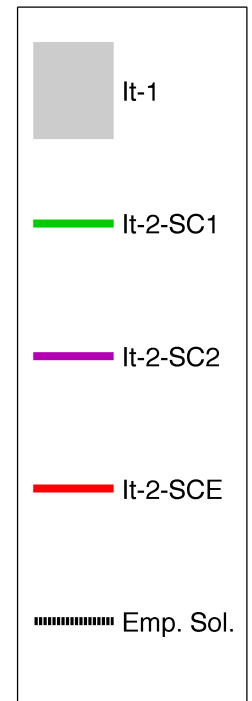
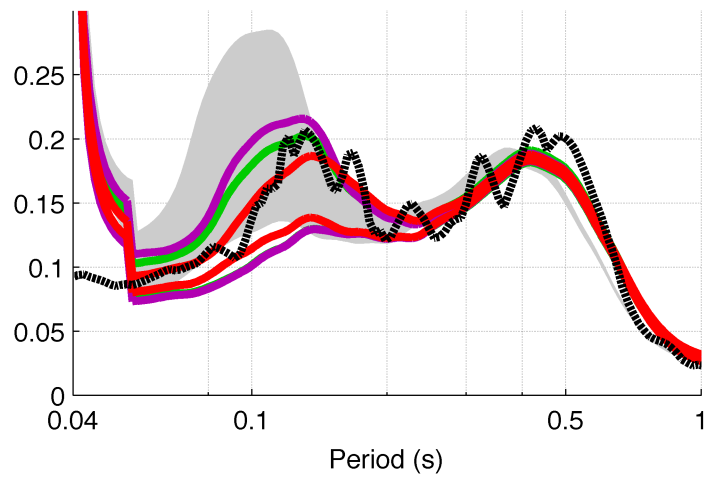
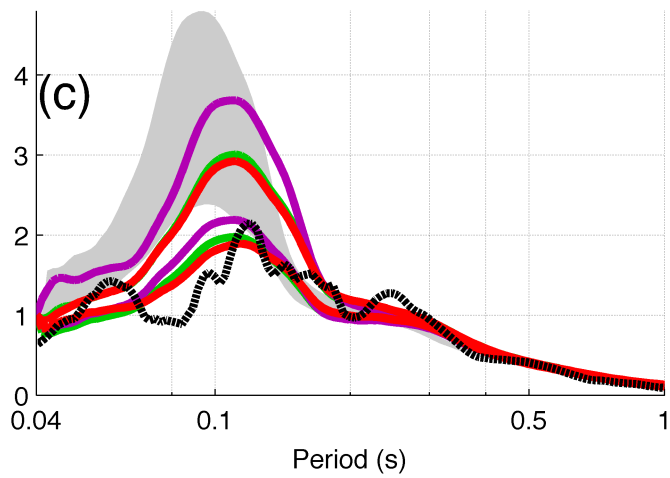
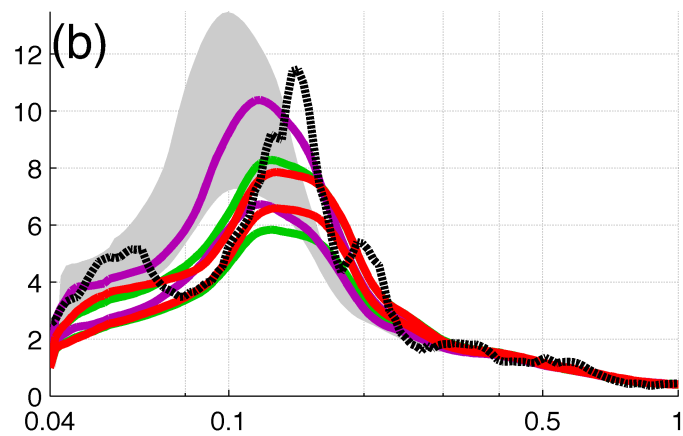
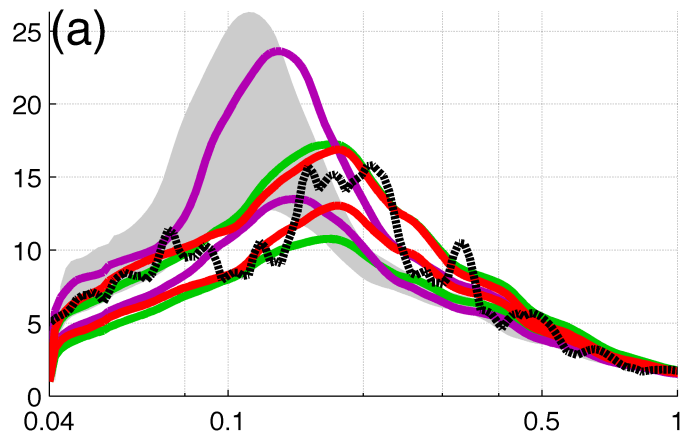
SA



SA



SA



Conclusions

NEED for iterations

- **What did we observe?**

Fit is improved from iteration-1 to iteration-2 or more...

- Elastic parameters calibration is very important
- Physical attenuation still needs to be implemented in most FEM codes

- **What is needed?**

- Field data to calibrate laboratory tests as well to study linear response of the soil column (borehole data is the best for this)
- The best results for this benchmark came when fitting observations. **Not a blind exercise anymore!**
 - *Low strain damping from weak motion recordings*
 - *NL curves from literature for similar soils (and strong motion response...)*
- Input motion: Frequency content is very important (this is source/site dependent)
- Soil properties : Large effects on the results
 - *(low-strain, NL curves)*
- USE of more than one nonlinear code to capture epistemic variability
- TRAINED people to use these codes