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

J. Régnier, [1] L.F. Bonilla[4] , P.Y. Bard[3], E. Bertrand[1], H. Kawase[2],
F. Hollender[5], M. Marrot[1] , D. Sicilia[6] and the PRENOLIN participants*

[1] CEREMA Dter Méditerranée, laboratoire de Nice
[2] Kyoto University
[3]ISTerre, Grenoble
[4] IFSTTAR, Marne-la-Vallée
[5] CEA, Cadarache
[6]EDF, Aix-en-Provence

* D.Assimaki (Gorgia tech), D. Boldini (Univ. Bologna), S.Iai (DPRI), S.Kramer (Univ. Washington), E.Foerster (CEA), C.Gélis (IRSN), G.Gazetas (NTUA), J.Gingery (Kleinfelder/UCSD), Y.Hashash (Univ. of Illinois), P.Moczo (CUB), S.Foti (Politecnico di Torino), G.Lanzo (Univ. Rome), F.Lopez-Caballero (ECP), D.Roten (ETHZ), K.Pitilakis (AUTH), F.DeMartin (BRGM), B.Jeremic (UCD), A.Nieto-Ferro (EDF), M.P.Santisi (Univ. Nice), D.Mercerat (CEREMA).

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

Switzerland :
- ETHZ, Zürich

USA:
- UCSD, California,
- UW, Washington,
- UCDavis, California,
- GATECH, Georgia,
- CEEI, Illinois

Japan:
- DPRI, Kyoto
- DPRI, Kyoto

Slovakia:
- UNIBA, Bratislava

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

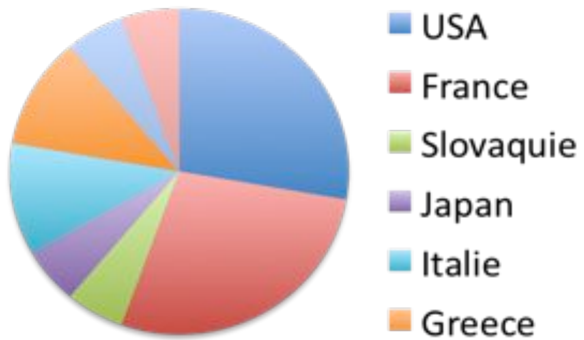
Italy:
- Univ. Bologna
- Univ. Roma
- Polito, Torio

Greece:
- AUTH, Thessaloniki
- NTUA, Athens

Equipes de modélisation
Co-organisateurs

Some additional information

Overview teams and codes

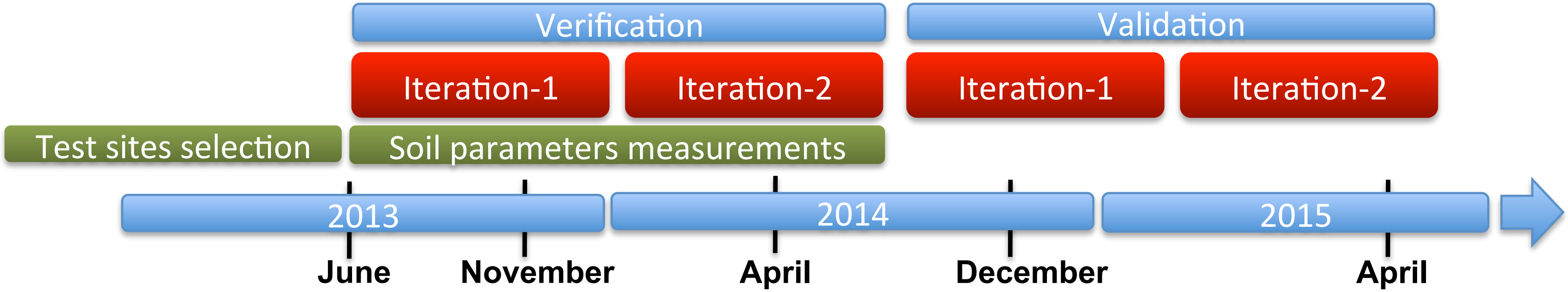


21 Participant teams / **26 Codes tested**

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 implemenation

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).

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).

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) **Philips and Hashash's model** (F-0, J-O, M-2, T-0),

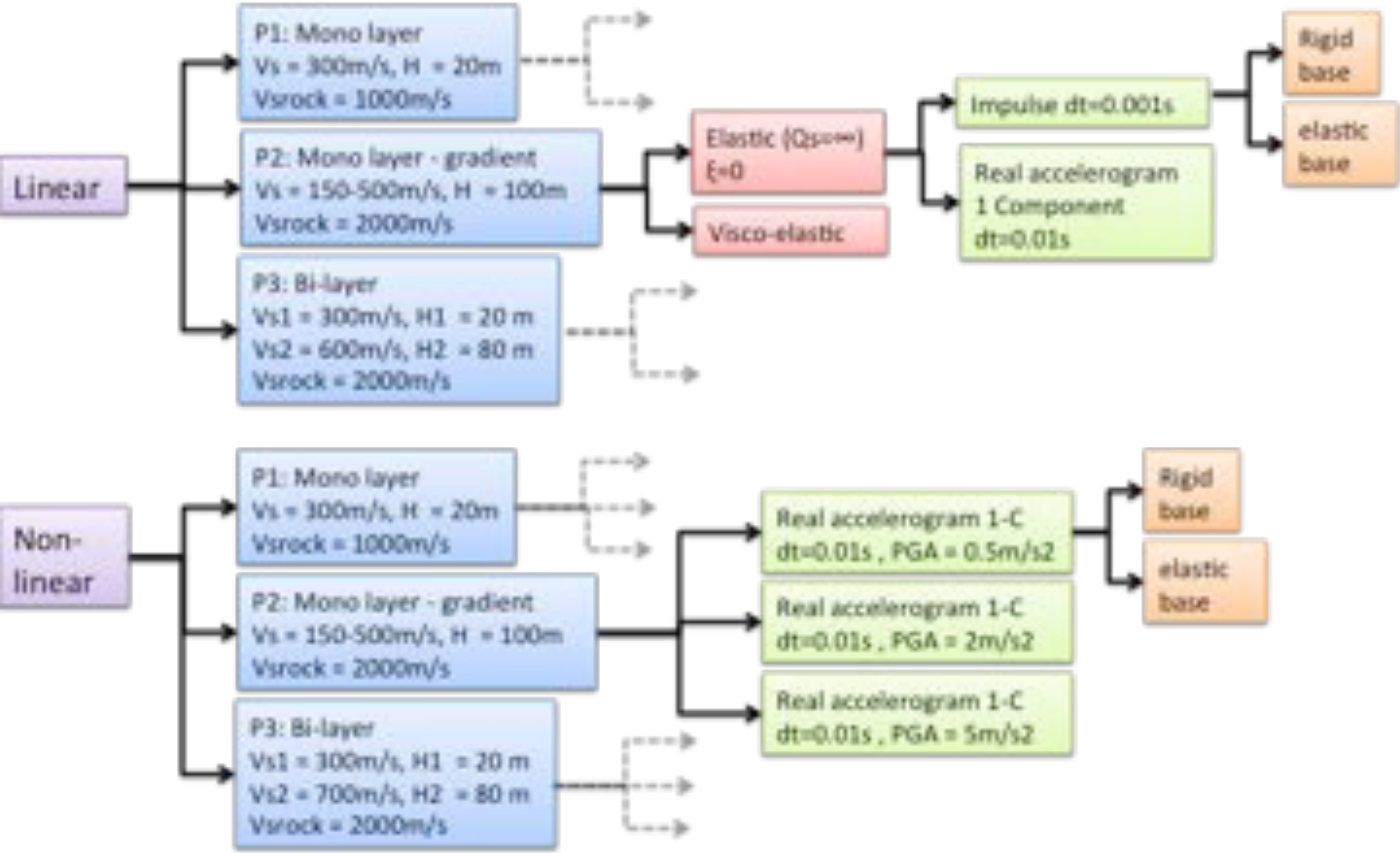
(iv) all other models.

Loading/unloading

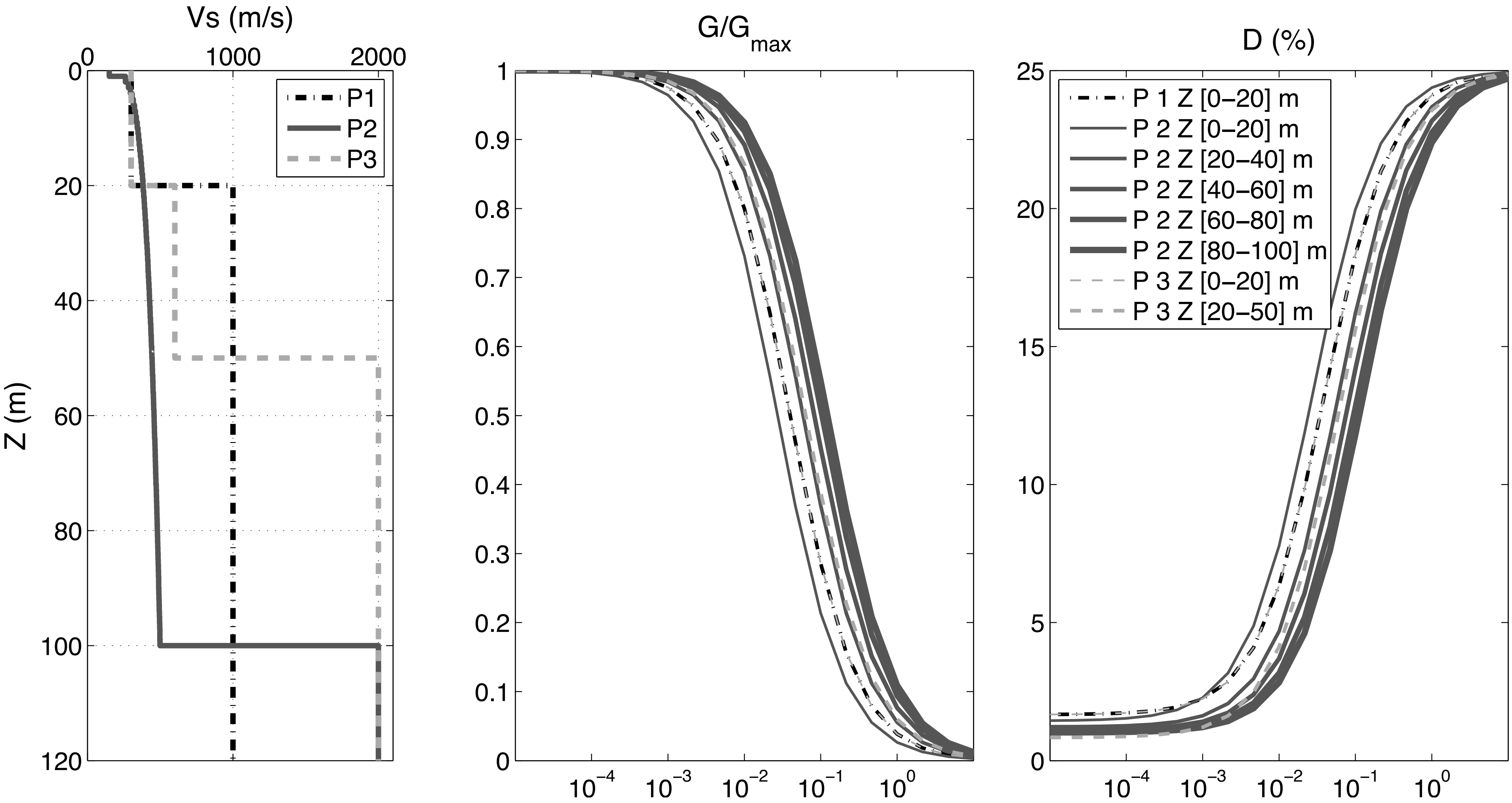
(i) **No masing** (A-0, B-0, E-0, J-0),

(ii) **Masing rule** (all other teams).

Idealistic cases



Idealistic cases: soil parameters

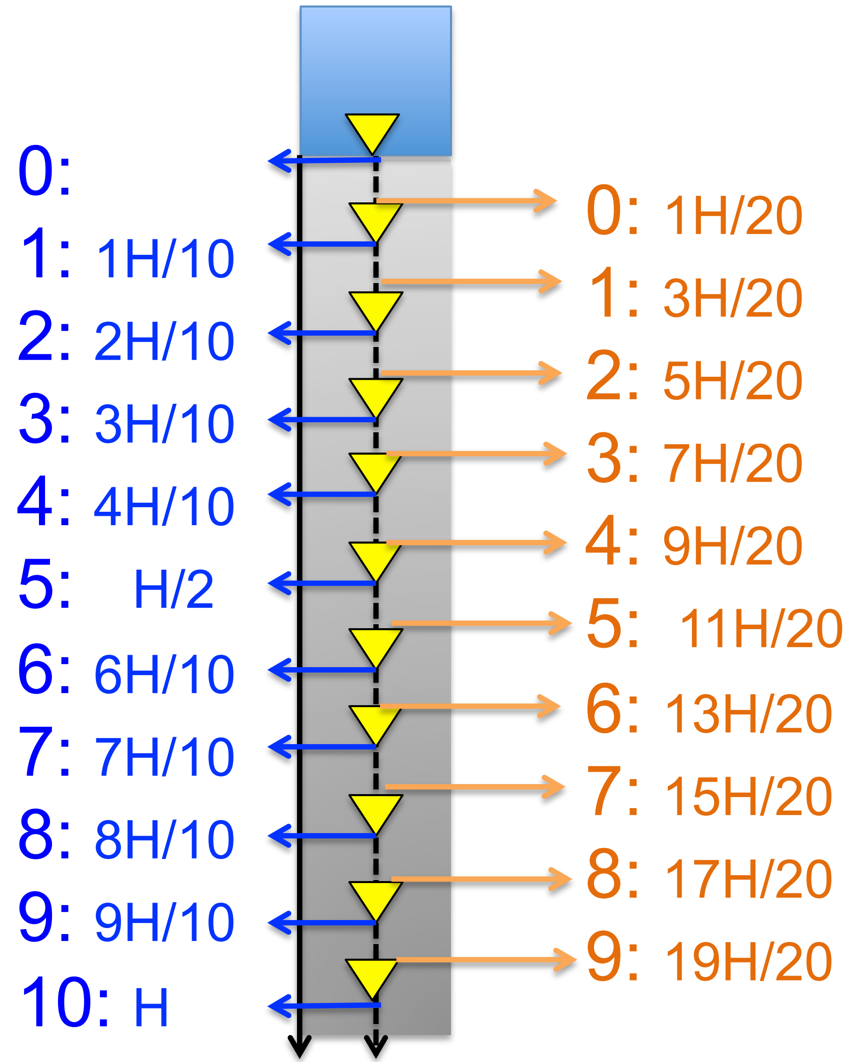


What did we ask for?

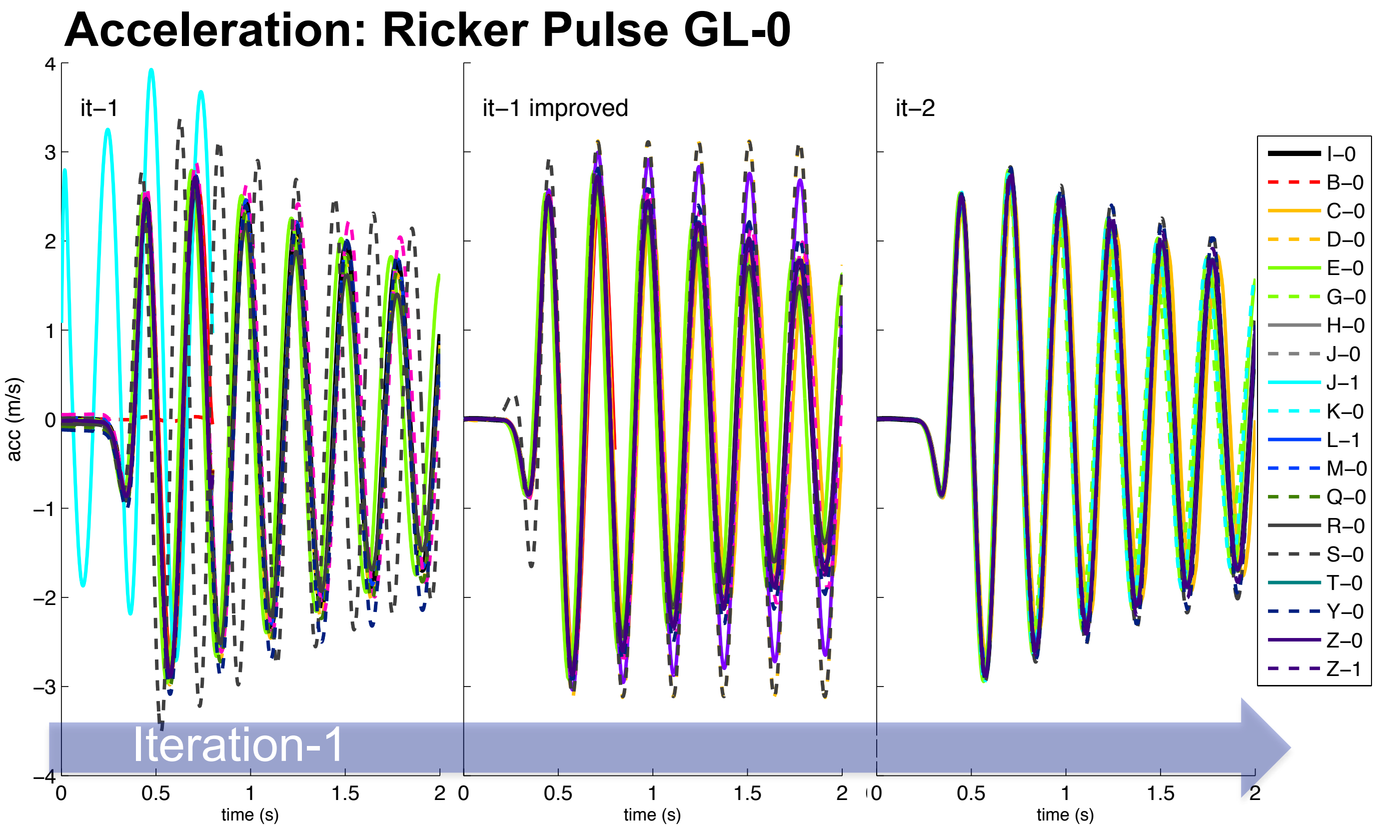
- **Acceleration THs a(t, z_i), Δt = 0.01s**
  - ✓ $Z_1 = 0$
  - ✓ Zn = H
  - ✓ Delta z = H/10

- **Strains γ(t, z_i)**
- **Stresses τ(t, z_i)**
  - ✓ Z_1 = H/20
  - ✓ Zn = 19H/20
  - ✓ Delta z = H/10

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



Results: Linear elastic and visco-elastic cases



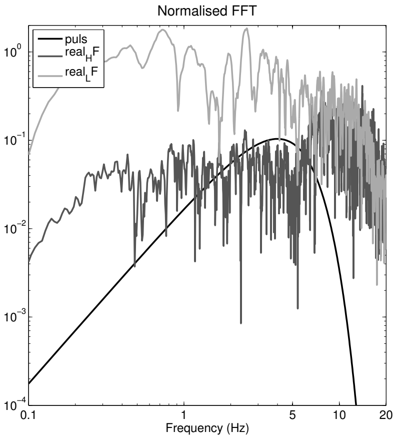
Profile: P1

Computation: **Visco-elastic**

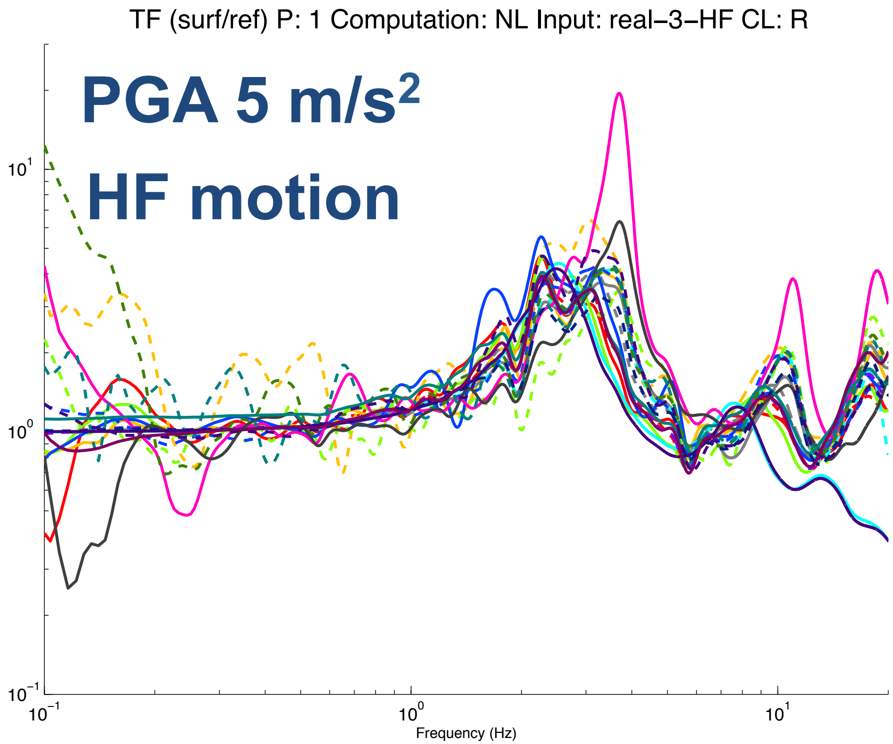
Condition sub: **Rigid**

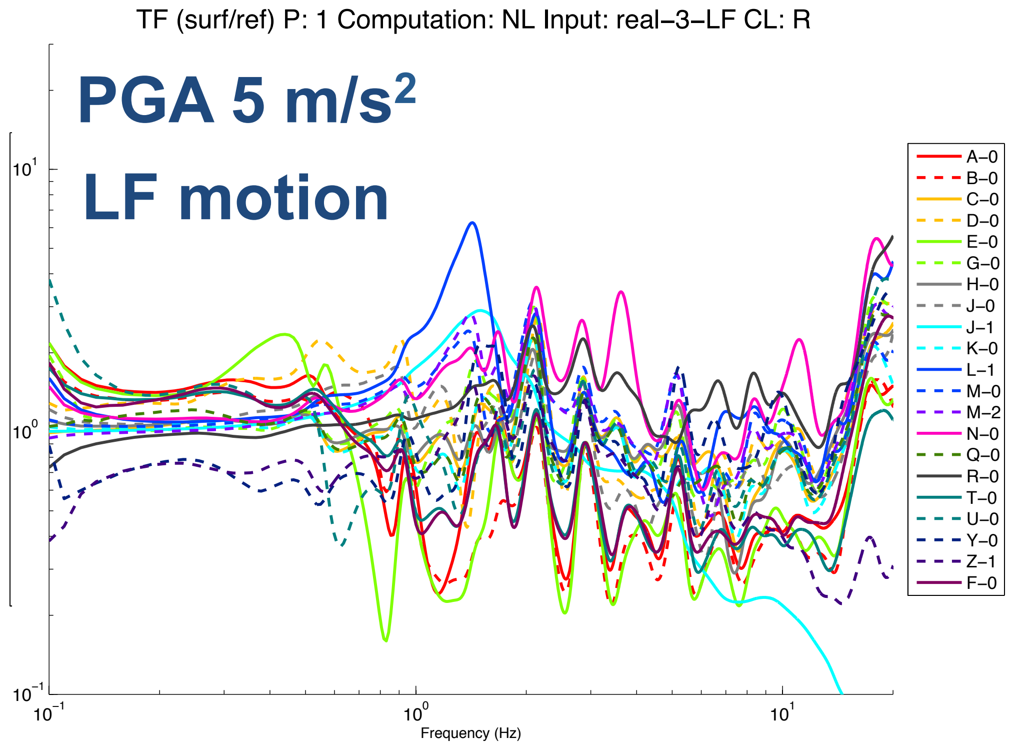
- From it-1 to it-2: Convergence almost achieved !
- Most of the divergences came from minor mistakes
  - Pb in units,
  - Pb of numerical dispersion
  - Pb of damping calibration (still to be done!)
  - Pb in input motion consideration and soil properties

Results: nonlinear computations



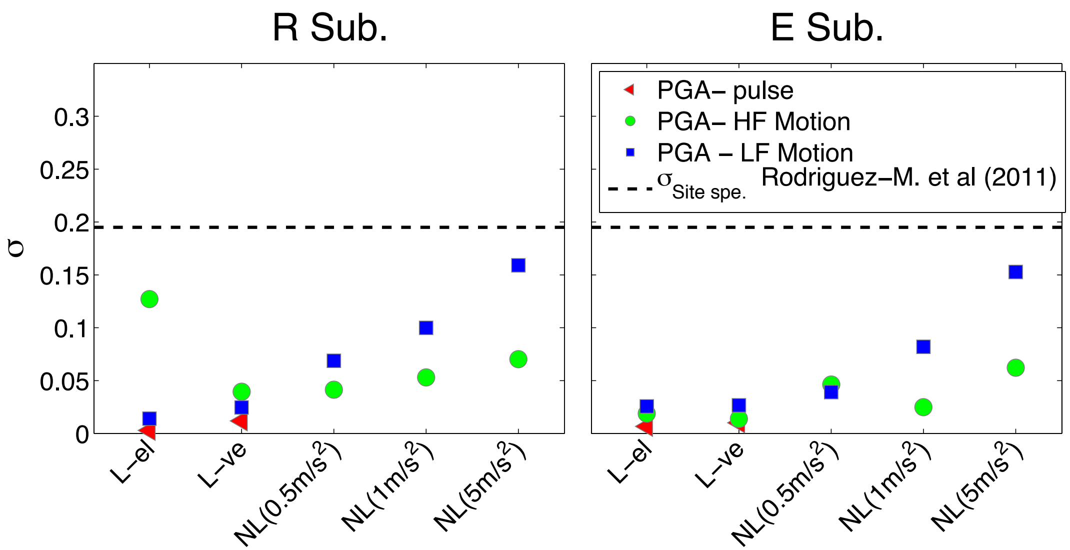
Variability and reference motion frequency content





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

Epistemic uncertainty: example P1

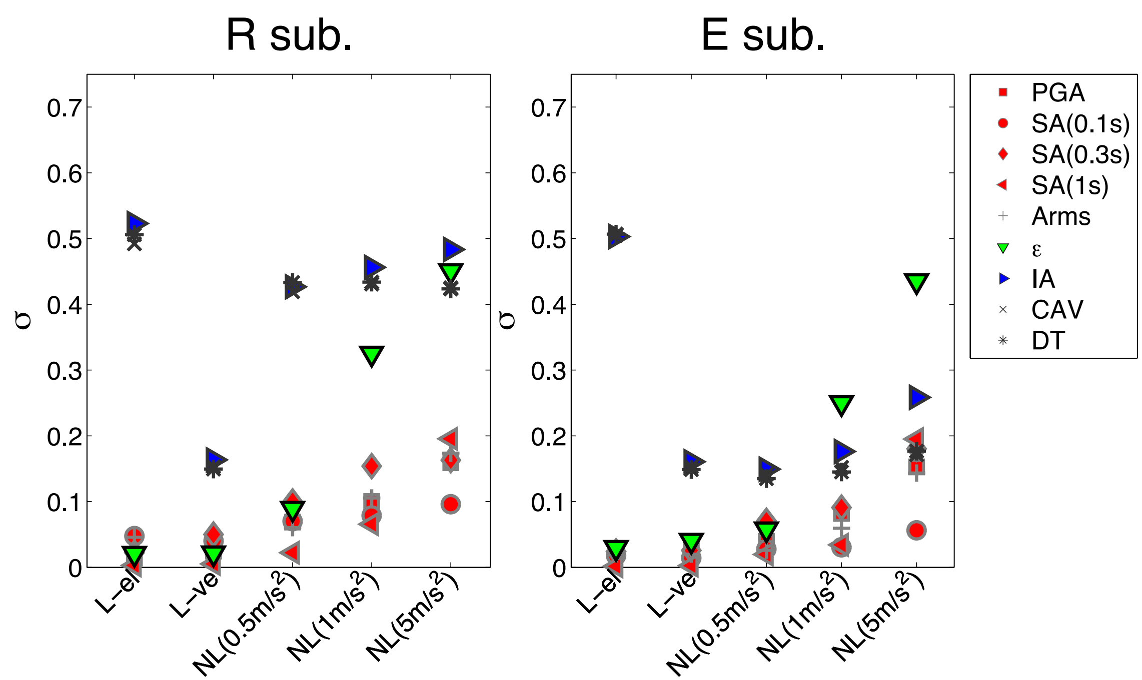


Standard deviation PGA

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

Standard deviation intensity parameters:

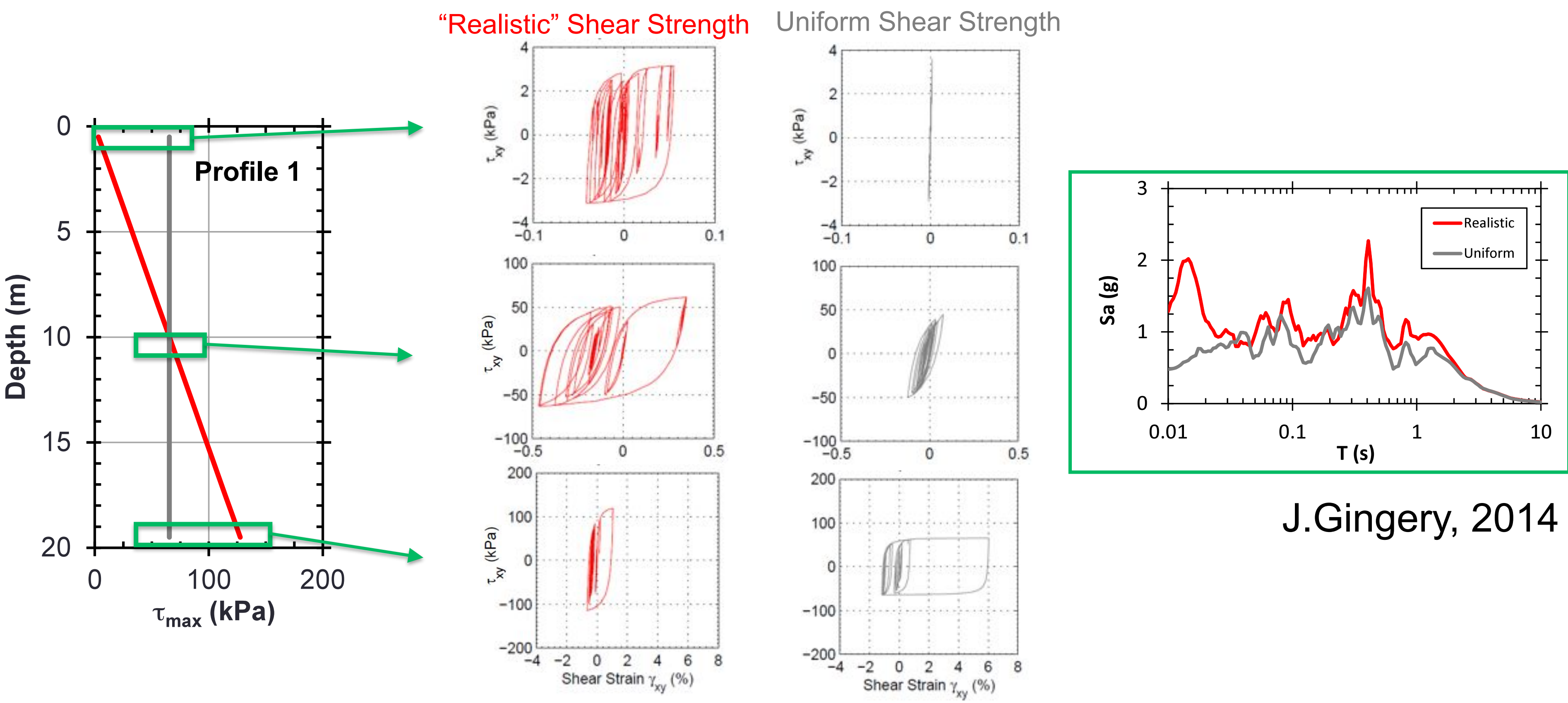
- R/E sub: Greater for duration based parameters (IA CAV DT) compare to peak values (PGA, SA, A_{rms})



Results: nonlinear computations

Can we reduce the epistemic uncertainty?

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

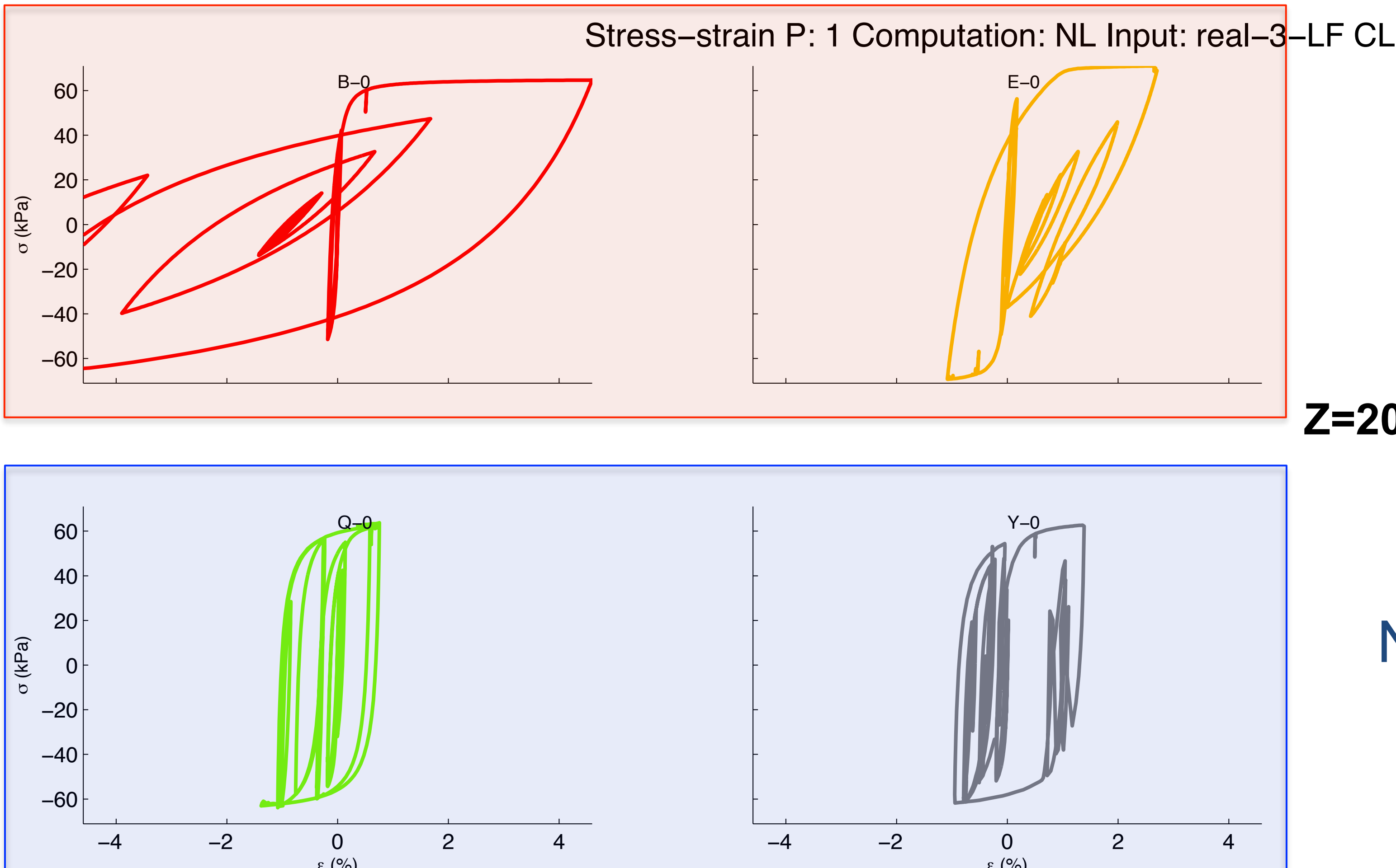


J.Gingery, 2014

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 ≠ codes same NL models



Damping control

Z=20m

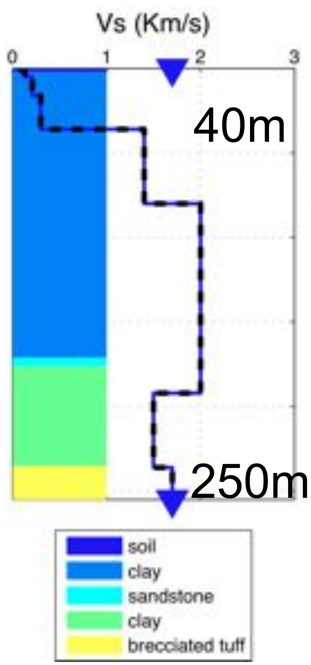
No Damping control

Site selection for VALIDATION phase

criteria

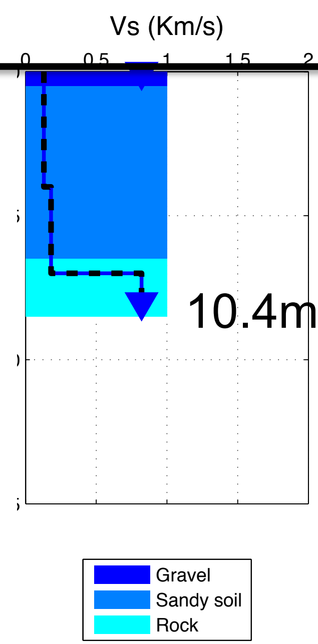
1- Sites with 1-D configuration
2- Sites having recorded weak and strong motion
3- Sites with non-linear soil behaviour (Cyclic mobility or not)

KSRH10: Kiknet site

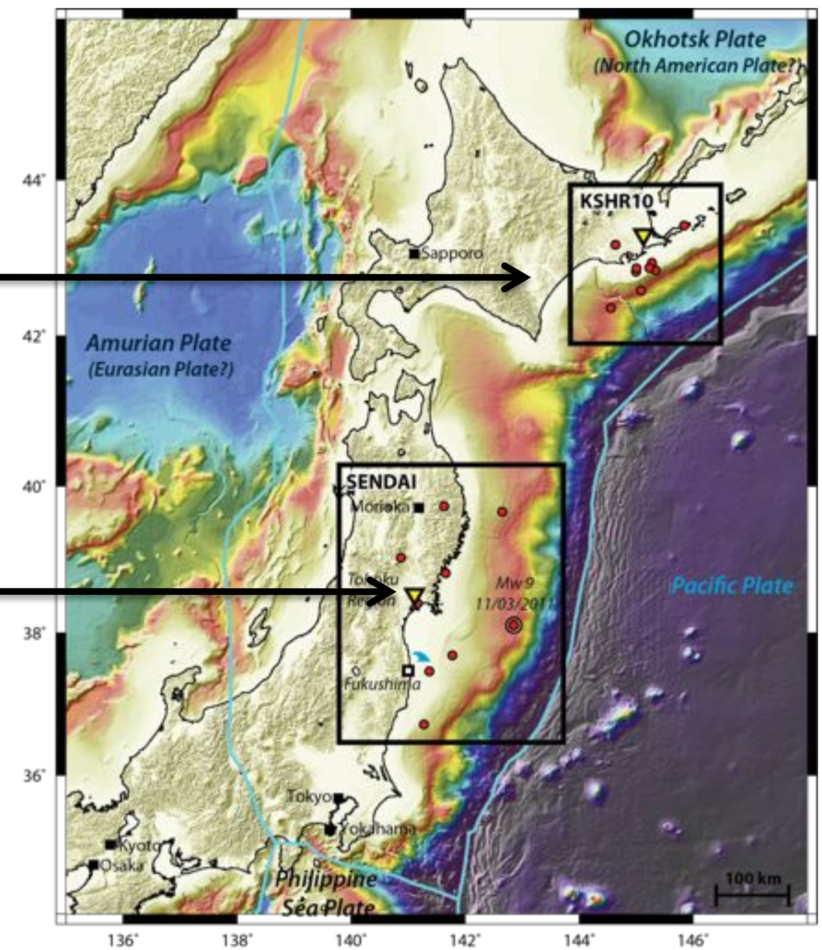


Deep site

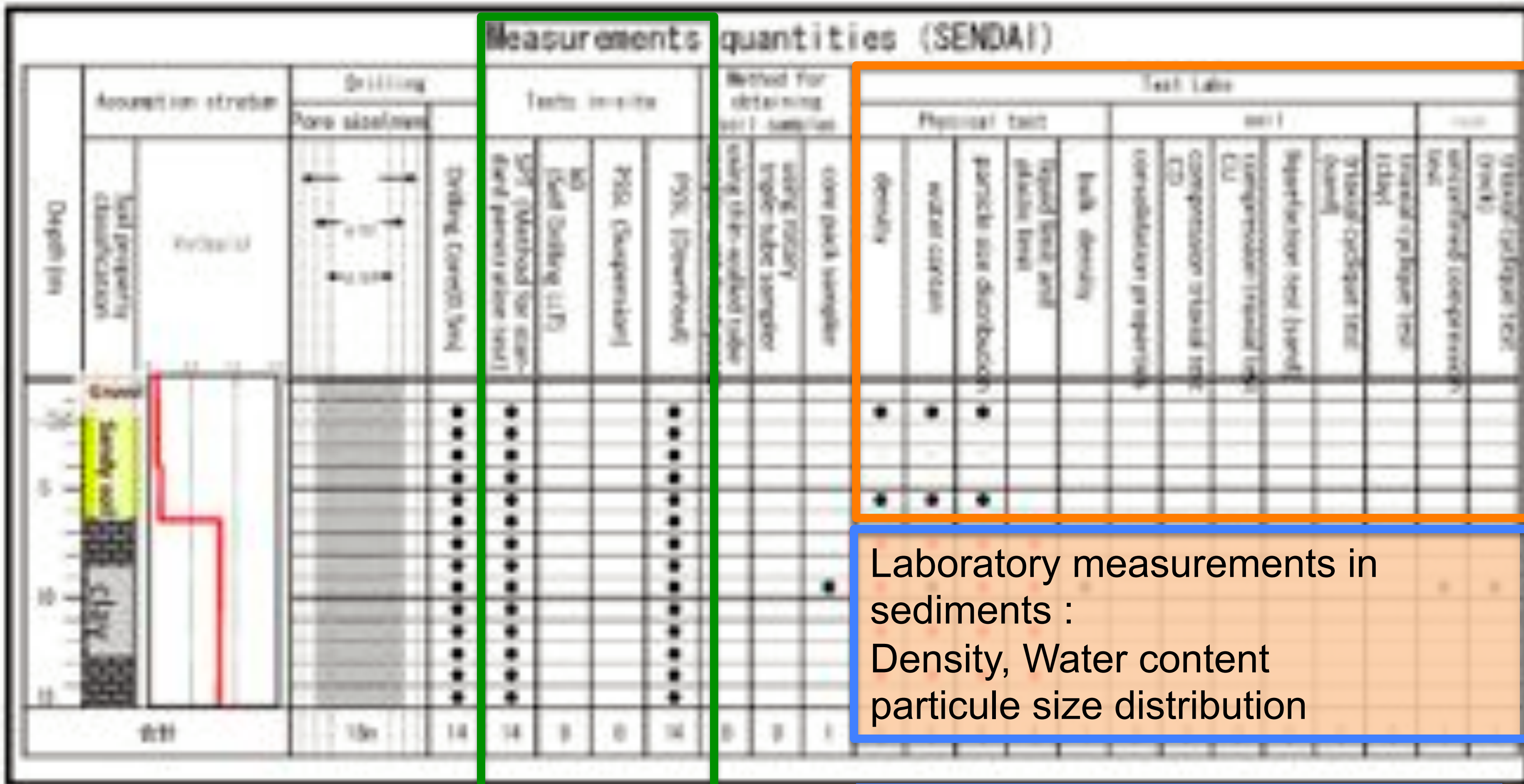
Sendai: PARI site



Shallow site



Site characterization: Example Sendai



+ multiple MASW lines

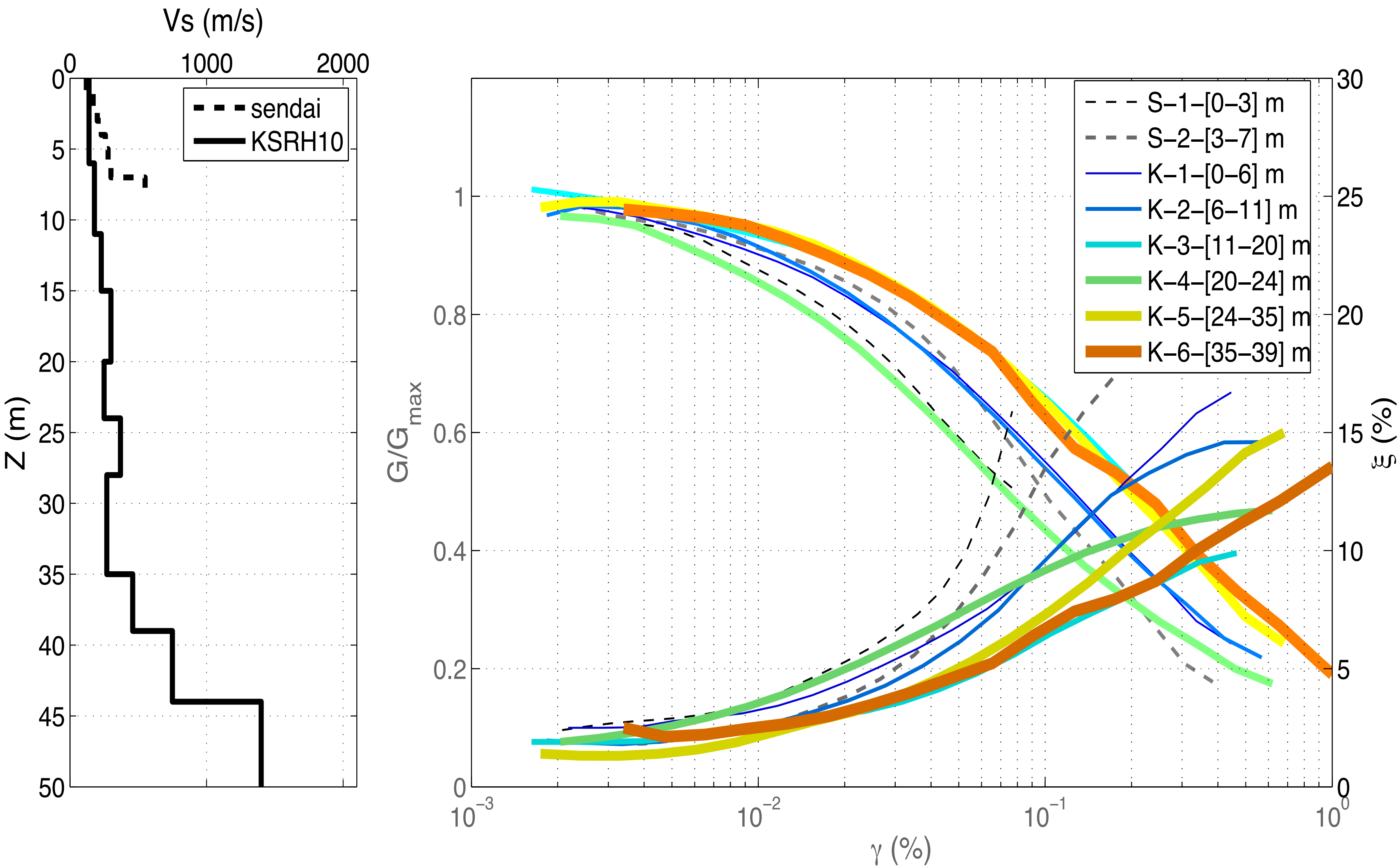
N-SPT

Vs

Laboratory measurements at rock:

- Bulk density
- Unconfined compressional test
- Triaxial cyclic test

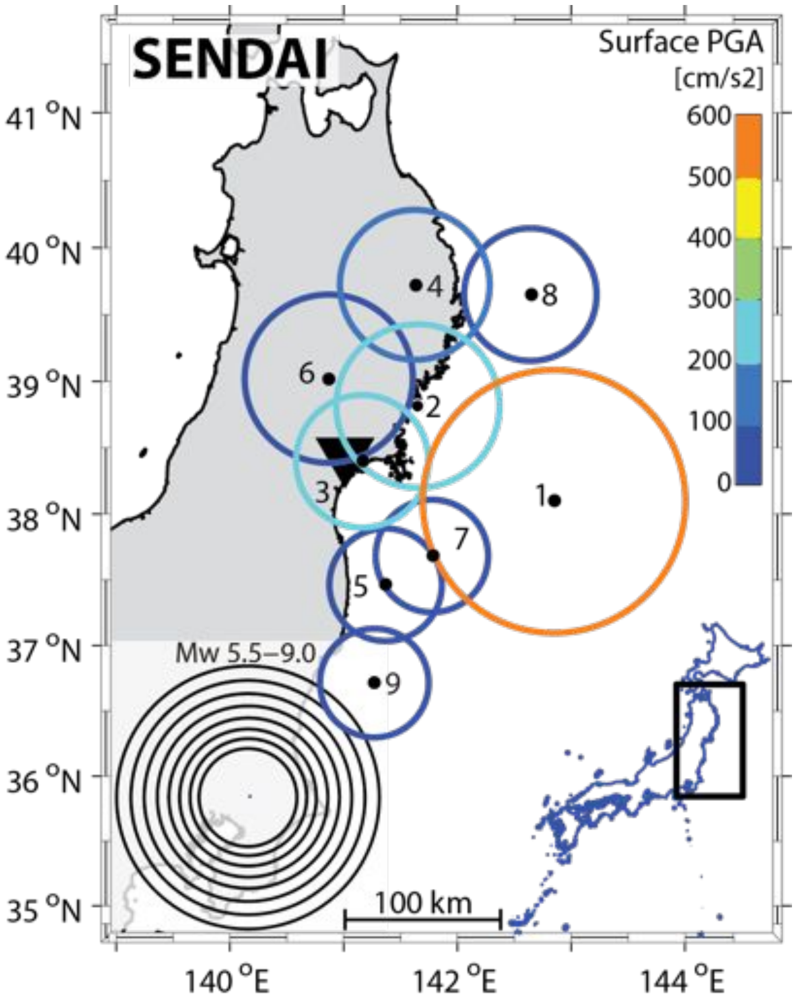
Soil parameters for the simulations

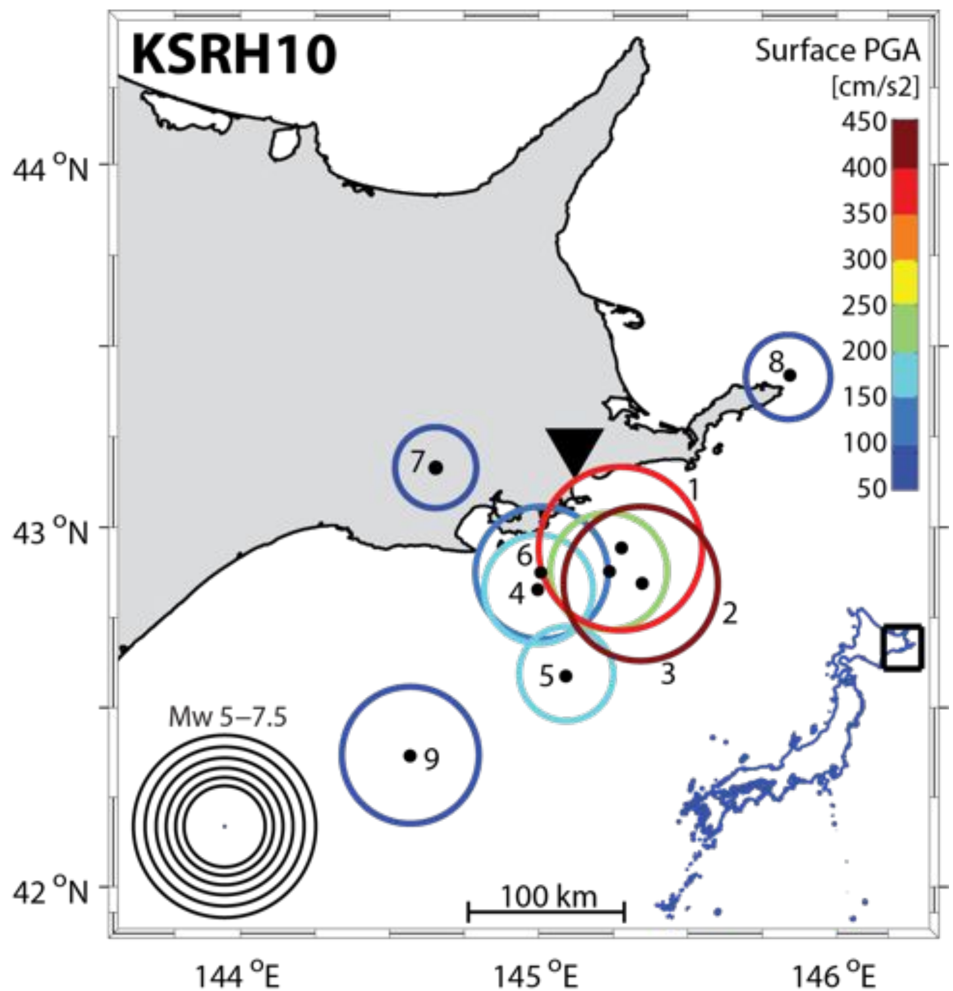


Input motion used

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

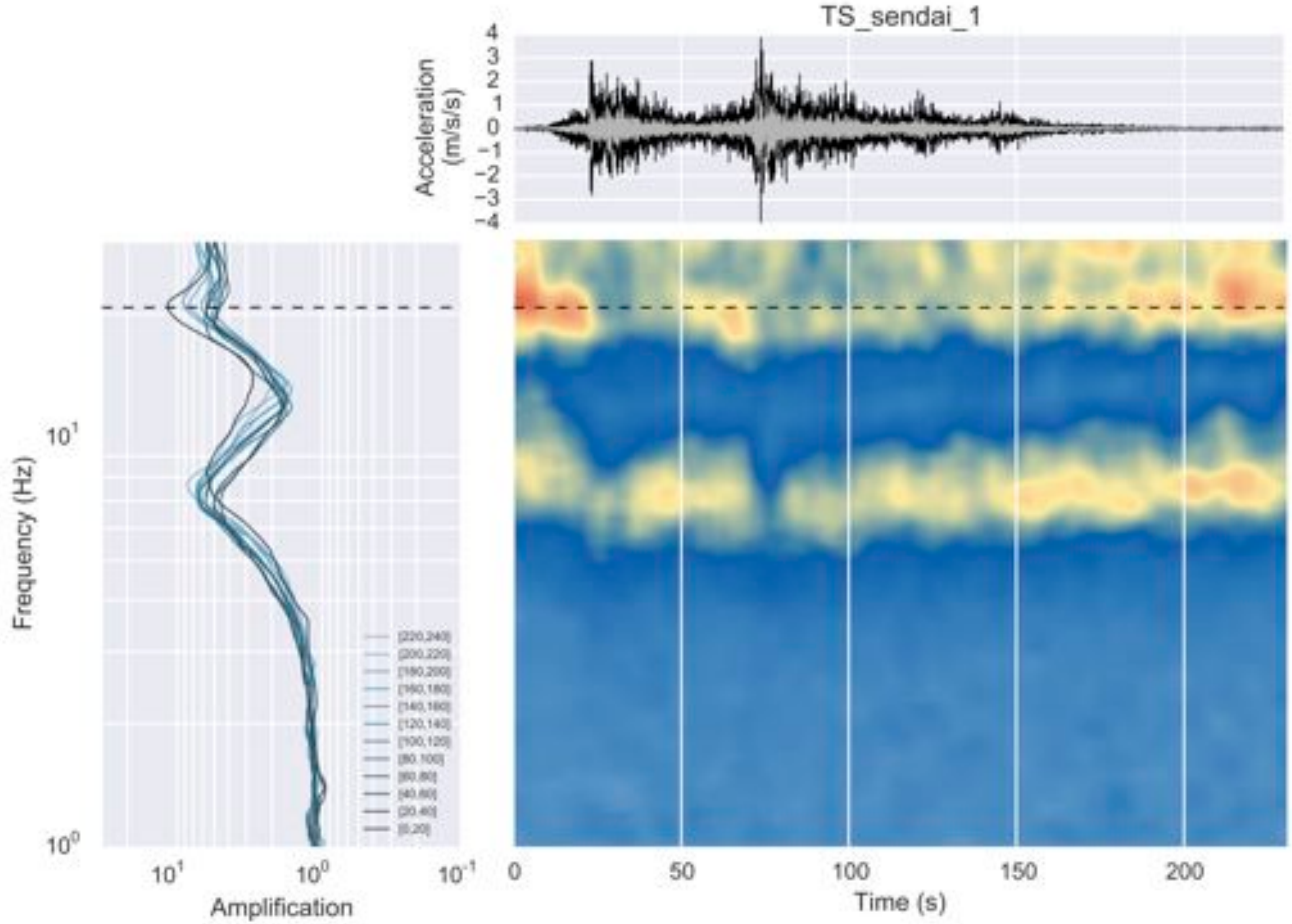
- **Sendai** PGA surf. From 10 to 400 cm/s^2
- **KSRH10** PGA surf. From 60 to 440 cm/s^2





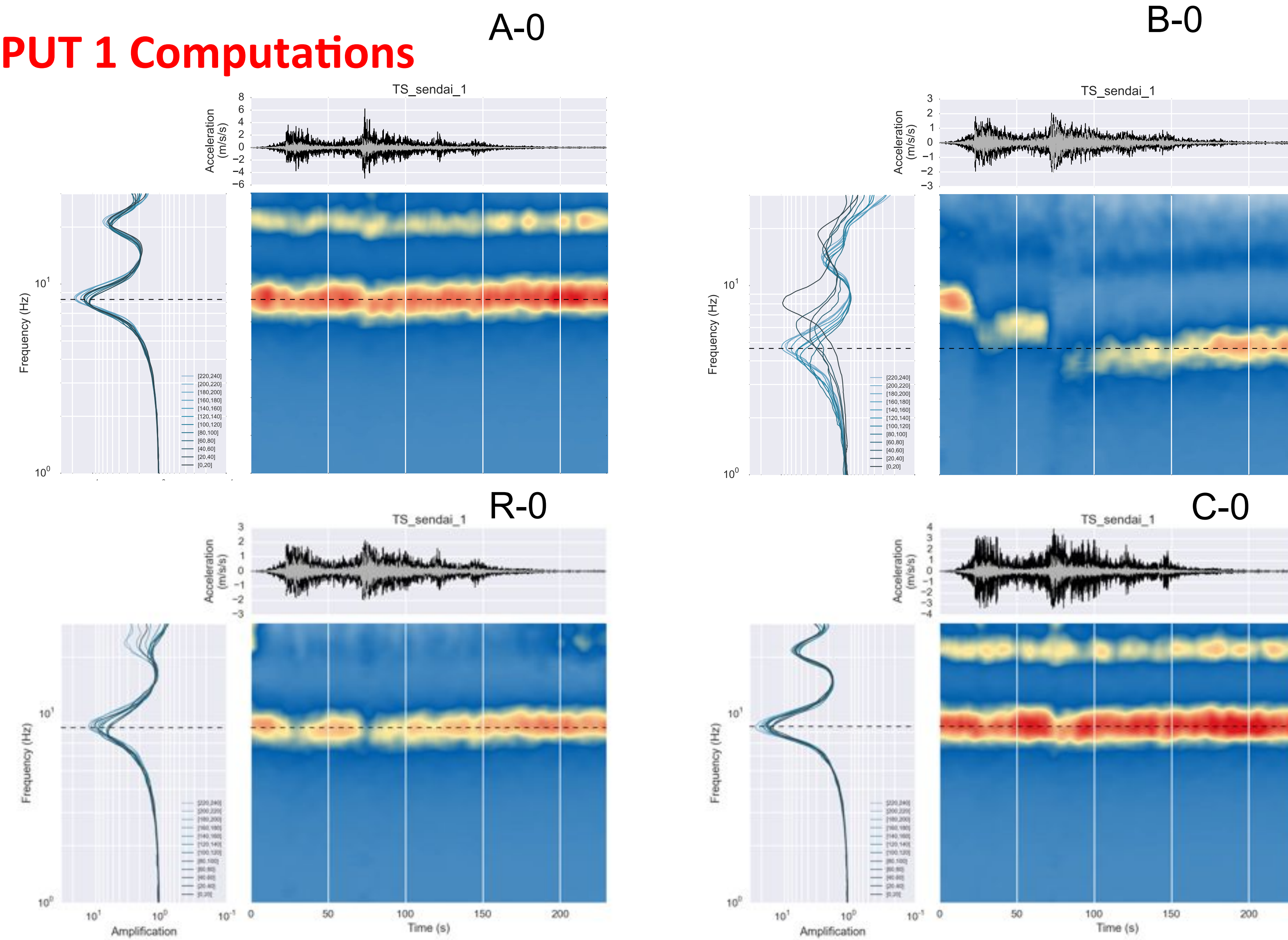
Time-dependent spectral ratio

INPUT 1 Observation



Time-dependent spectral ratio

INPUT 1 Computations



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:

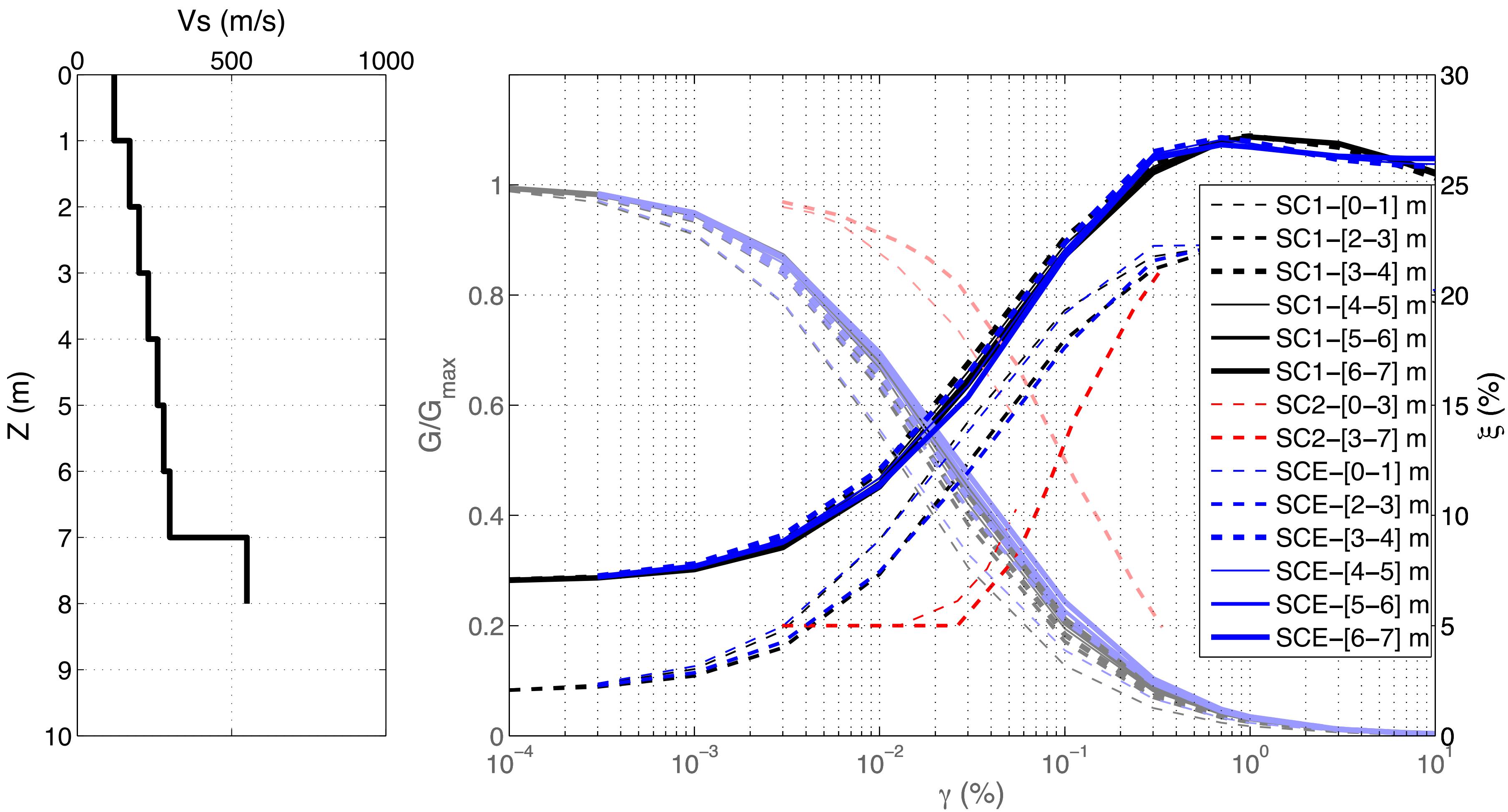
- ** **Uncertain or inadequate soil parameters**
- * **Non-vertically incident plane S waves**
- * **Component-to-component coupling not accounted for in 1D, single component computations**
- * **Non-1D soil conditions** (2D or 3D)

(**) 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

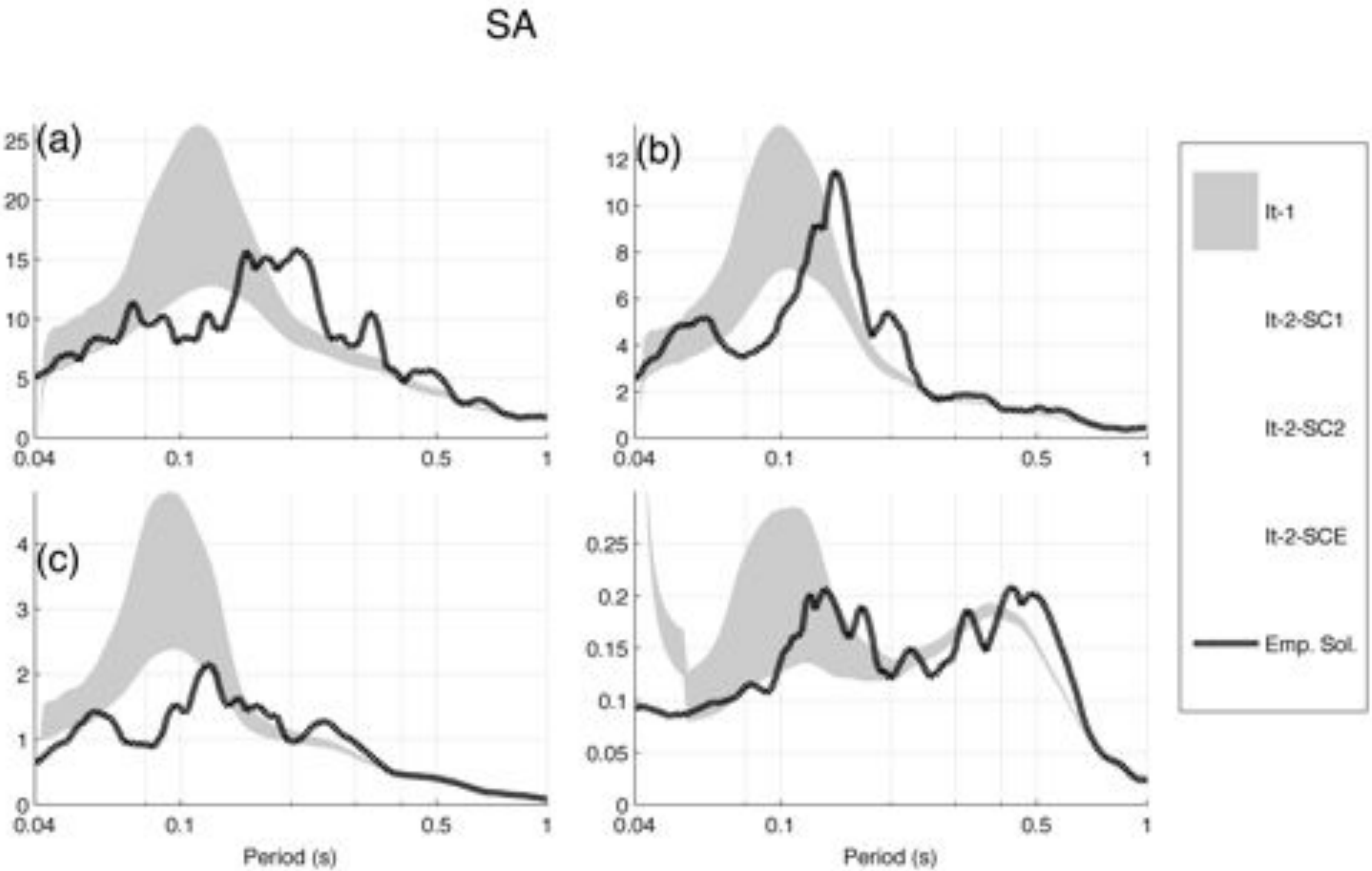
New calculations to be performed

Imposed and preferred models

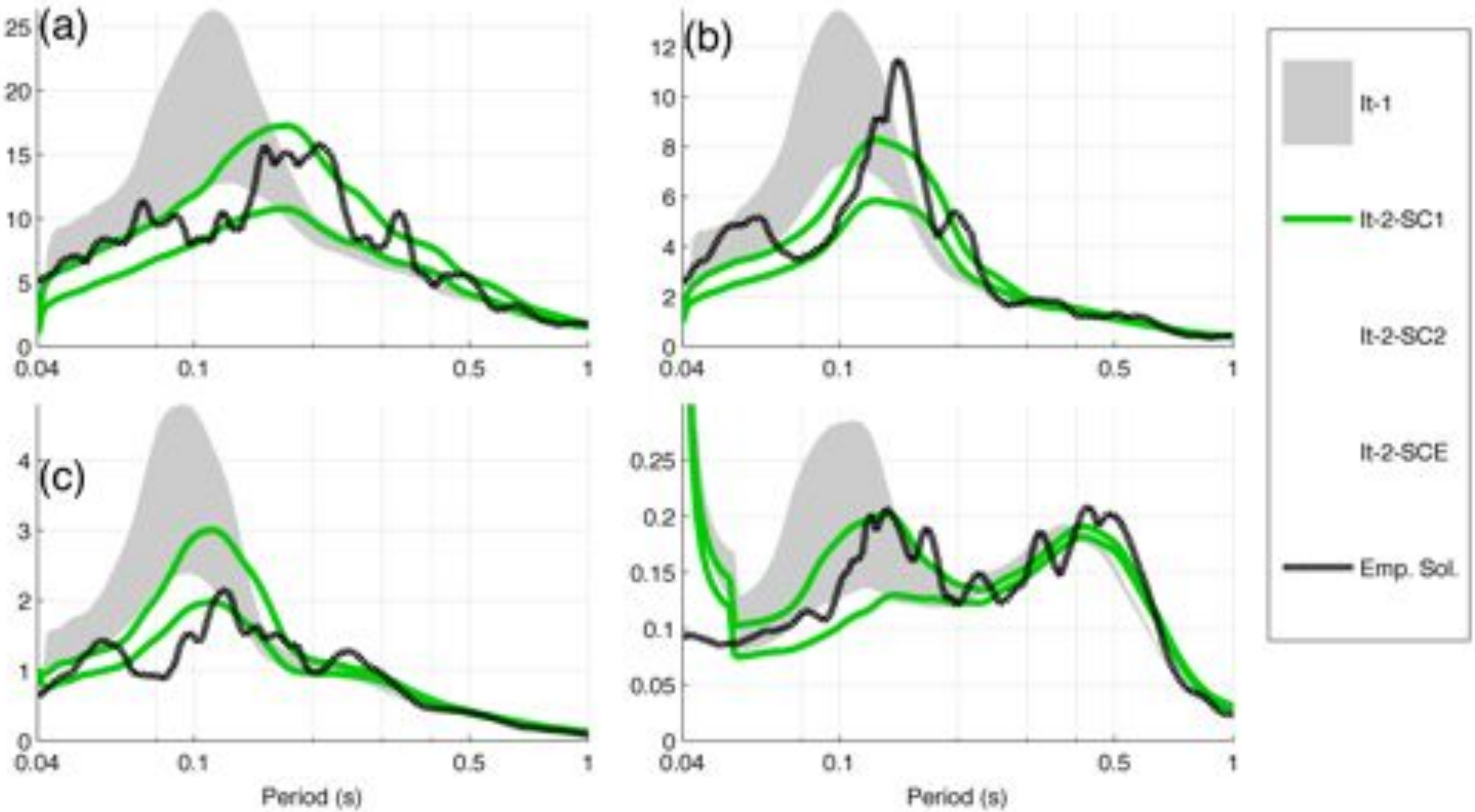


Team J did effective stress analysis

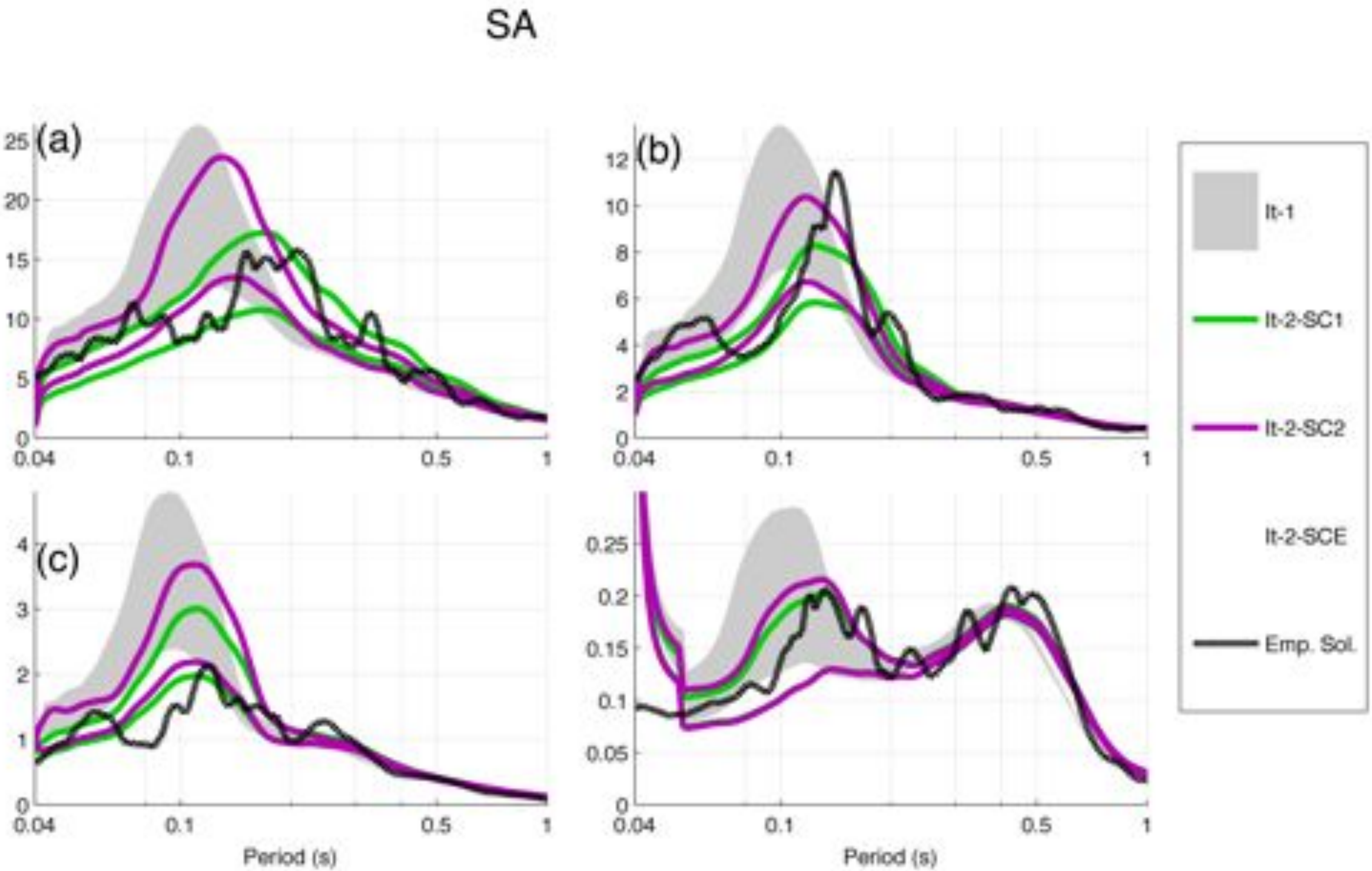
Envelope of the results



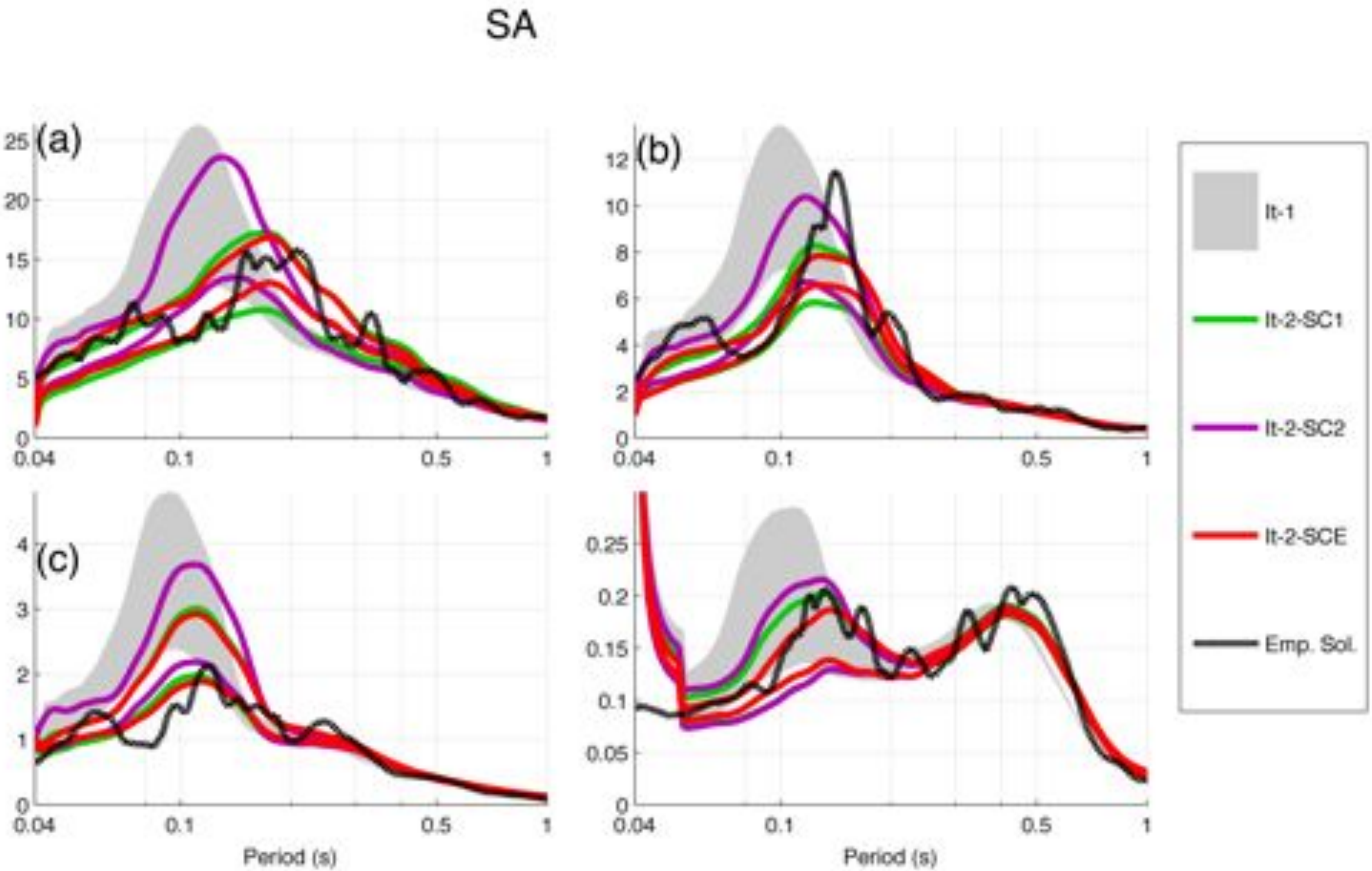
SA



(a)
(b)
(c)
25
20
15
10
5
0
12
10
8
6
4
2
0
4
3
2
1
0
0.25
0.2
0.15
0.1
0.05
0
0.04
0.1
0.5
1
Period (s)
Period (s)
It-1
It-2-SC1
It-2-SC2
It-2-SCE
Emp. Sol.



SA
(a)
(b)
(c)
It-1
It-2-SC1
It-2-SC2
It-2-SCE
Emp. Sol.
Period (s)
Period (s)



SA
(a)
(b)
(c)
25
20
15
10
5
0
12
10
8
6
4
2
0
4
3
2
1
0
0.25
0.2
0.15
0.1
0.05
0
0.04
0.1
0.5
1
Period (s)
It-1
It-2-SC1
It-2-SC2
It-2-SCE
Emp. Sol.

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