Propagation of uncertainty in the nonlinear site amplification

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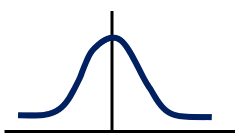
SEISMIC HAZARD ANALYSIS

SITE RESPONSE

- Nonlinear soil behavior
  - Linear-equivalent
  - Fully nonlinear
- Selection of input motions

DSHA

Fixed soil properties



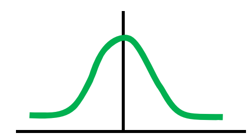
μ, σ

SITE PROFILE + INPUT MOTION

PSHA

Sources of uncertainty

Heterogeneity of soil profile
Ground motion selection



μ, σ

SITE RESPONSE

How uncertainties in a specific site profile generate uncertainties in the site response using the visco-hyplastic model?

Motivation

SEISMIC HAZARD ANALYSIS

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- Nonlinear soil behavior
  - Linear-equivalent
  - Fully nonlinear
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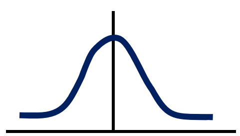

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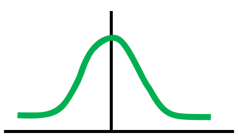


μ, σ

SITE RESPONSE

How uncertainties in a specific site profile generate uncertainties in the site response using the visco-hyplastic model?

Outline

- CONSTITUTIVE MODEL
- METHODOLOGY
- RESULTS
- CONCLUSIONS

Hypoplasticity:

$$\overset{o}{\mathbf{T}} = \mathbf{H}\left(\mathbf{T}, \mathbf{D}, e, \mathbf{h}\right)$$

$$\overset{o}{\mathbf{T}} = \mathsf{L} : \mathbf{D} + \mathbf{N}\left\|\mathbf{D}\right\|$$

$\overset{o}{\mathbf{T}}$: Co-rotated Zaremba-Jauman stress rate

$\mathbf{D}$: Strain rate tensor

L : 4th order tensor associated to the linear part of the eq.

$\mathbf{N}$: 2nd order tensor associated to the nonlinear part of the eq.

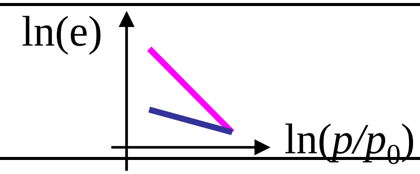
Visco-hypoplasticity (including Intergranular strain):

$$\boxed{\overset{o}{\mathbf{T}} = f_b \mathsf{M} : \mathbf{D} - \mathsf{L} : \mathbf{D}^{vis}}$$

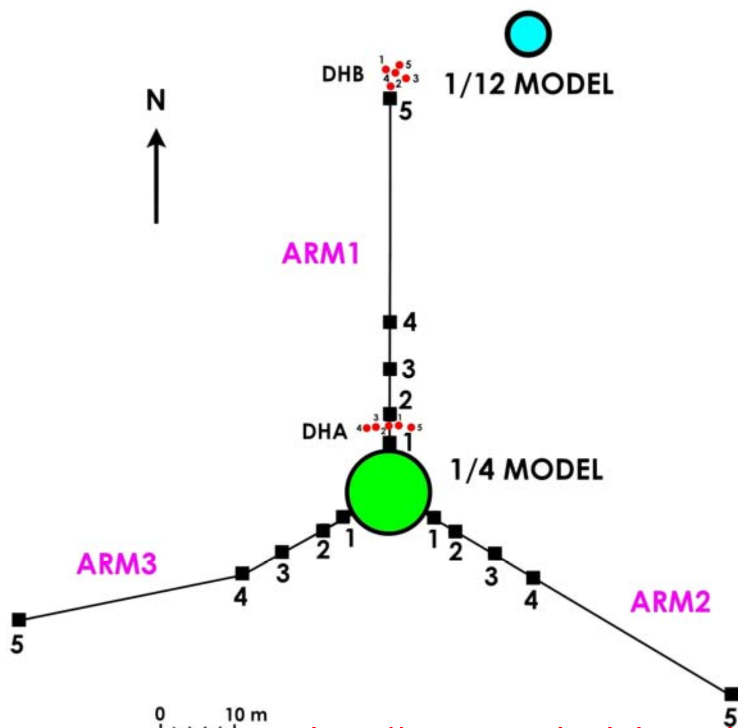
f_{b} : Barotropy function.

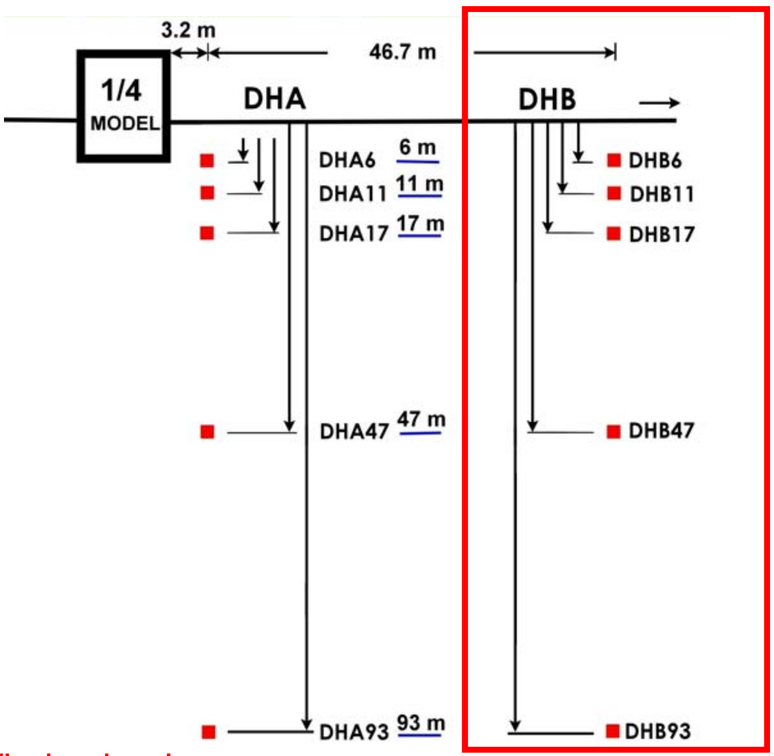
M : Fourth order tensor that represent the tangential stiffness

Constitutive Model
Parameters

Visco-hypoplasticity	
φ_c	Critical friction angle
λ	Normal consolidation line 
κ	Recompression line
β_R	Control parameter for generation of pore pressure considering an ellipsoidal yield surface
I_v	Viscosity index
D_r	Reference creep rate
e_{100}	Void ratio for p =100 kPa on the isotropic consolidation line
Intergranular strain	
m_R,m_T	Characteristic stiffness for a strain path reversal (180°) and transversal direction (90°)
R	Radius of elastic range
χ	Material constant used for interpolation
β_x	Material constant which controls the rate of **h**

- Case study: Large Scale Seismic Test LSST Lotung (Taiwan):
  - ✓ U.S Electric Power Research Institute (EPRI) + Taiwan Power Company (1985)
  - ✓ 2 model structures: 1/4-scaled and 1/12–scaled
  - ✓ 2 downhole arrays: DHA and DHB
  - ✓ 3 component accelerometers
  - ✓ 18 earthquake records: Sept 1985 – Nov 1986



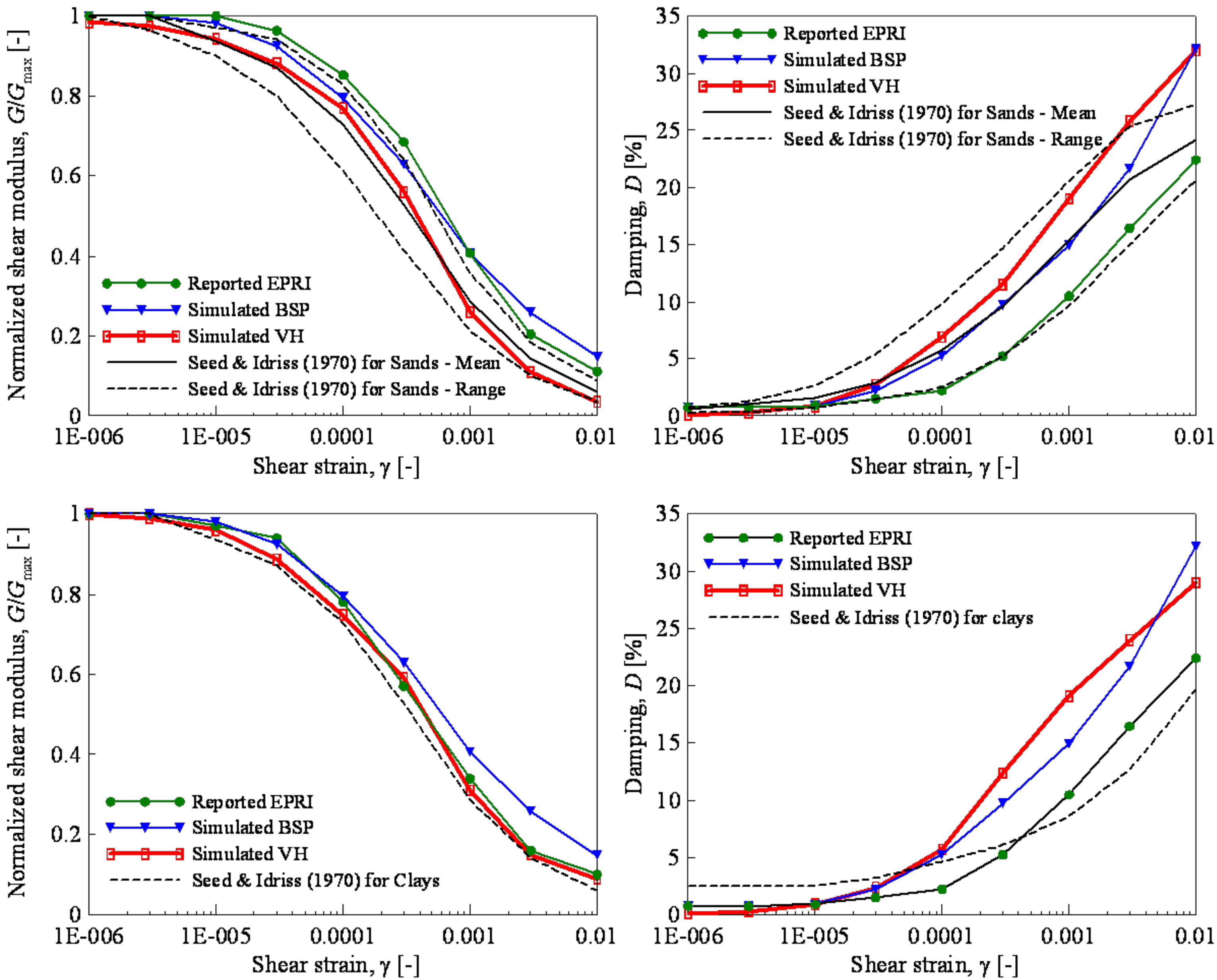


http://www.earth.sinica.edu.tw/en/index.html

Site Response Using a Visco-hypoplastic model

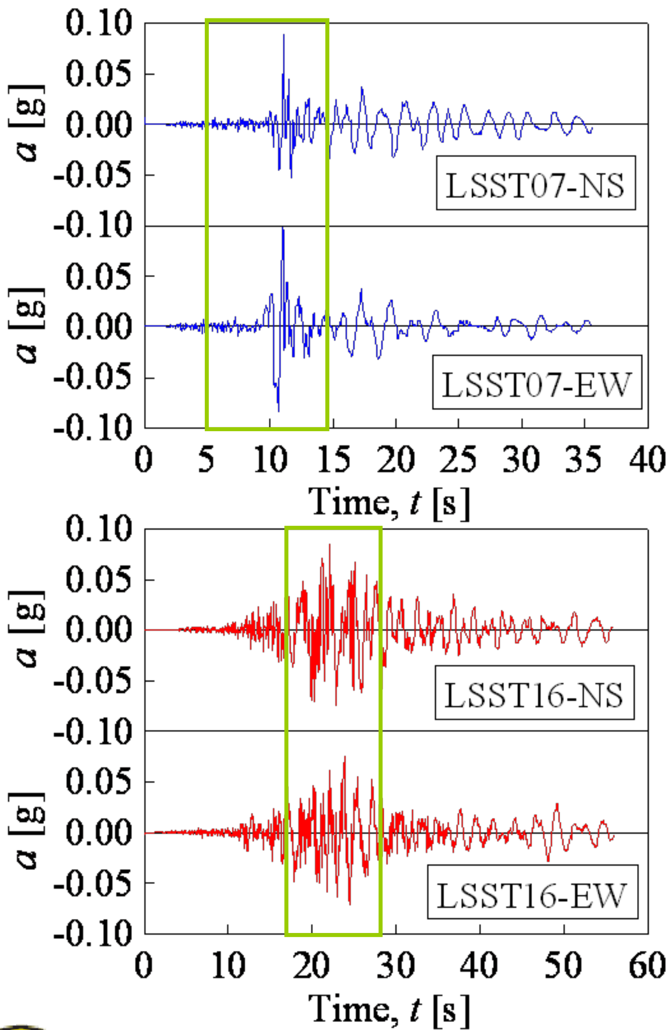
Granular soils

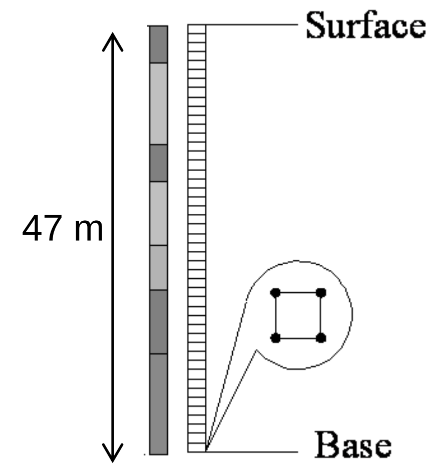
Fine-grained soils



- Implementation of the constitutive model:

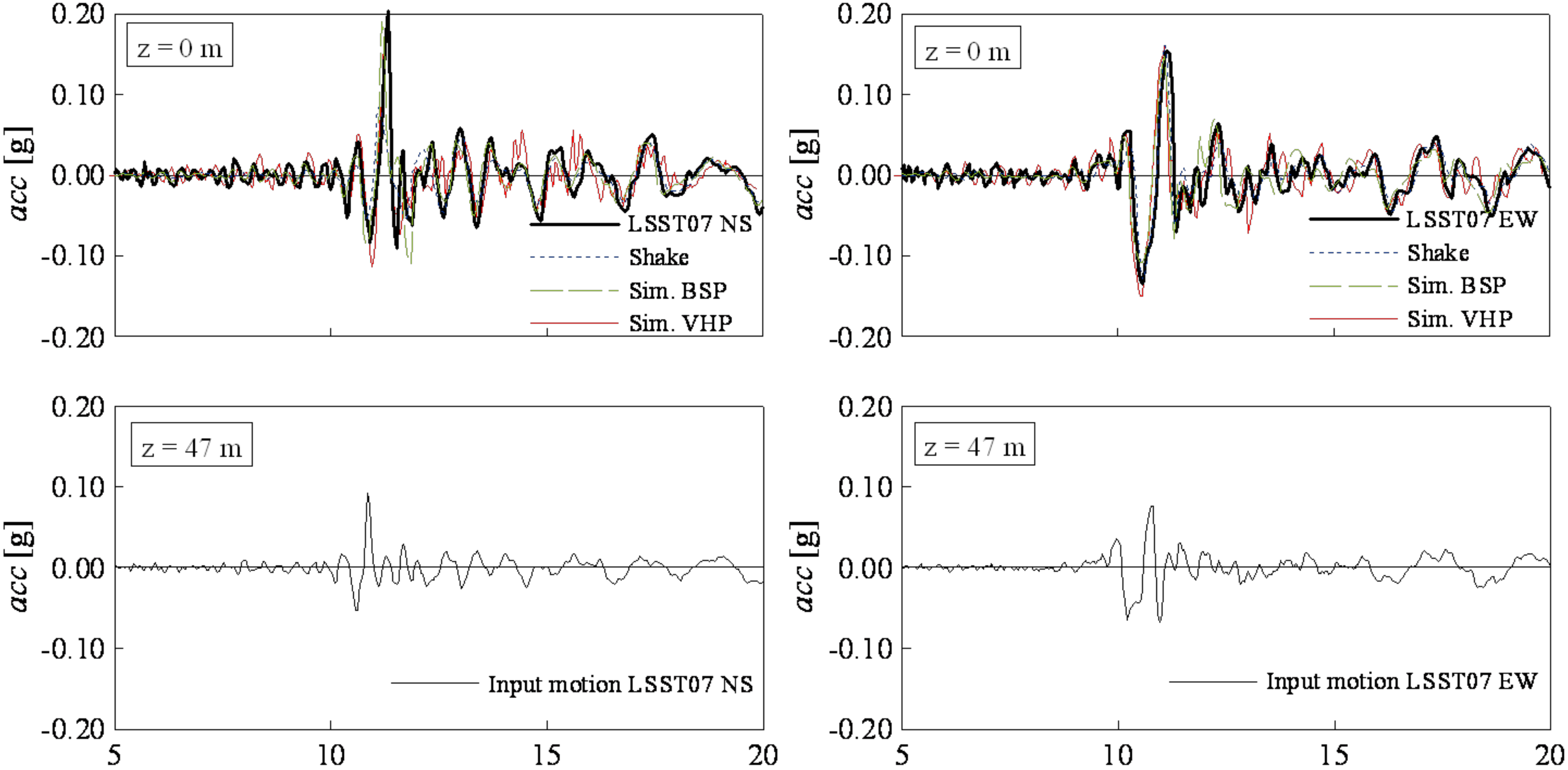
ABAQUS + user-defined subroutine



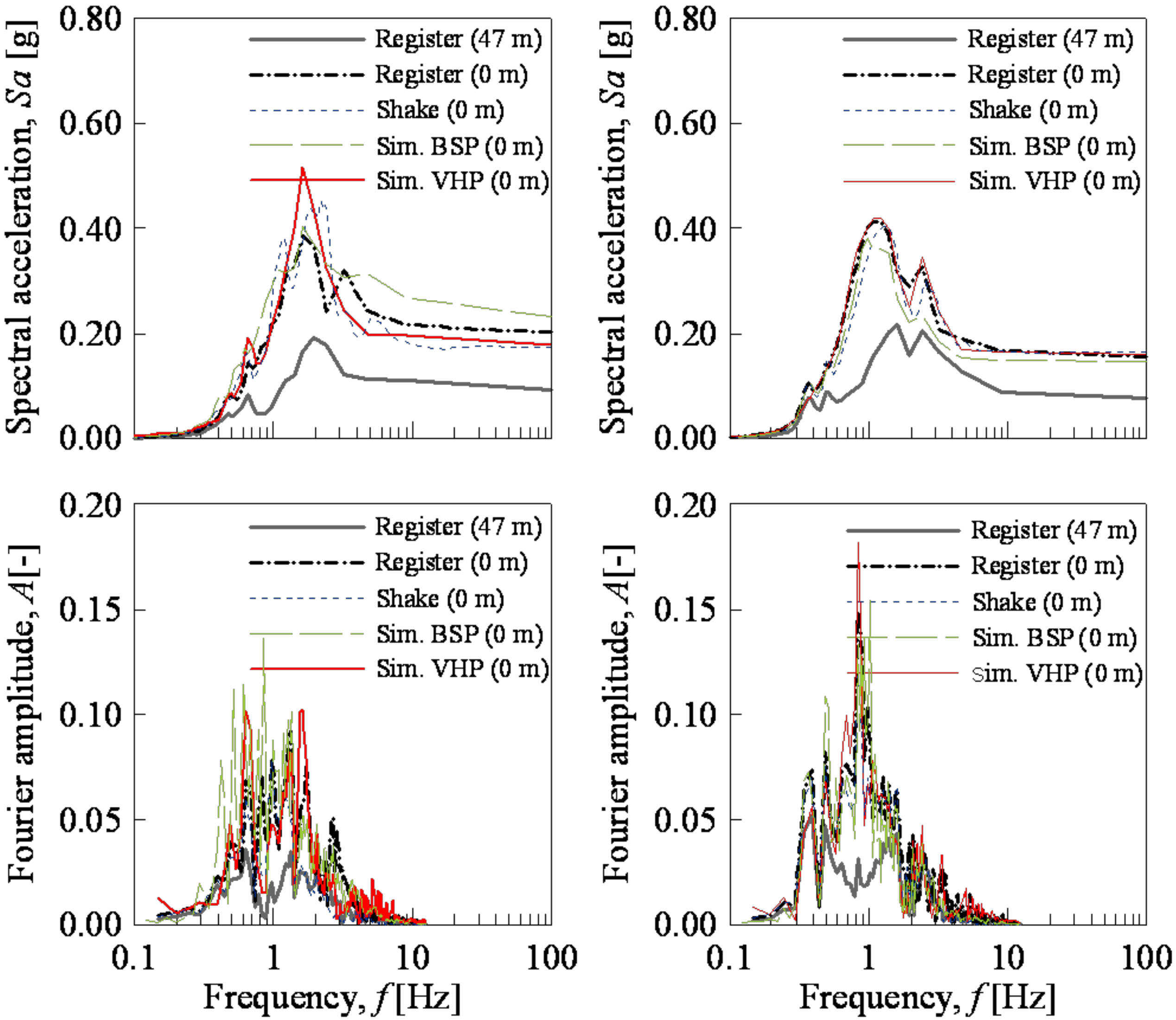


EVENT	LSST07	LSST16
Date	05/20/1986	11/14/1986
Closest distance [km]	64	39
Moment Magnitude [M_w]	6.4	7.3
Focal depth [km]	15.8	6.9
PGA, NS [g]	0.207	0.17
PGA, EW [g]	0.156	0.13
Time increment, Δt [s]	0.04	0.04

- Results LSST07



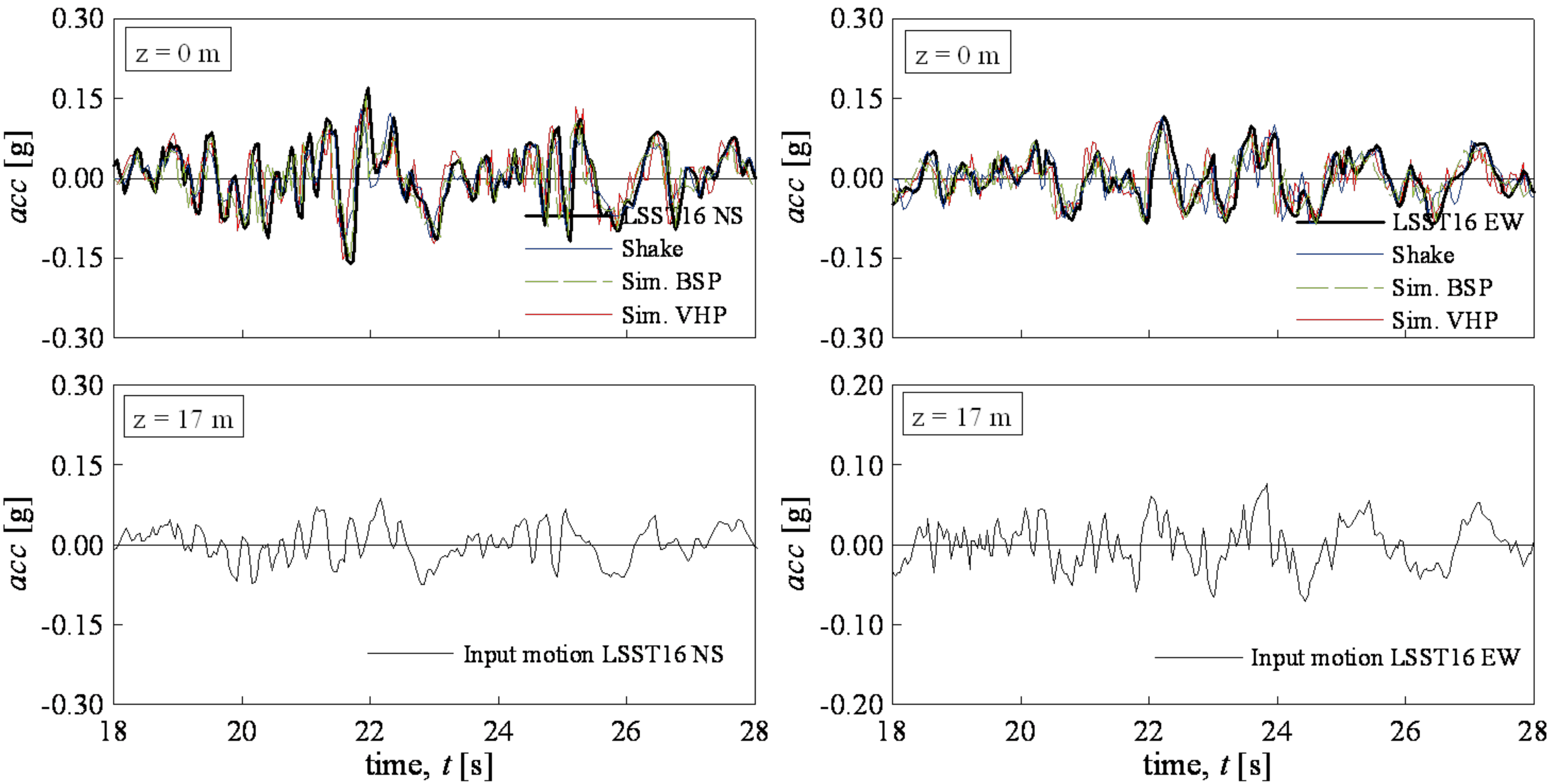
Site Response Using a Visco-hypoplastic model



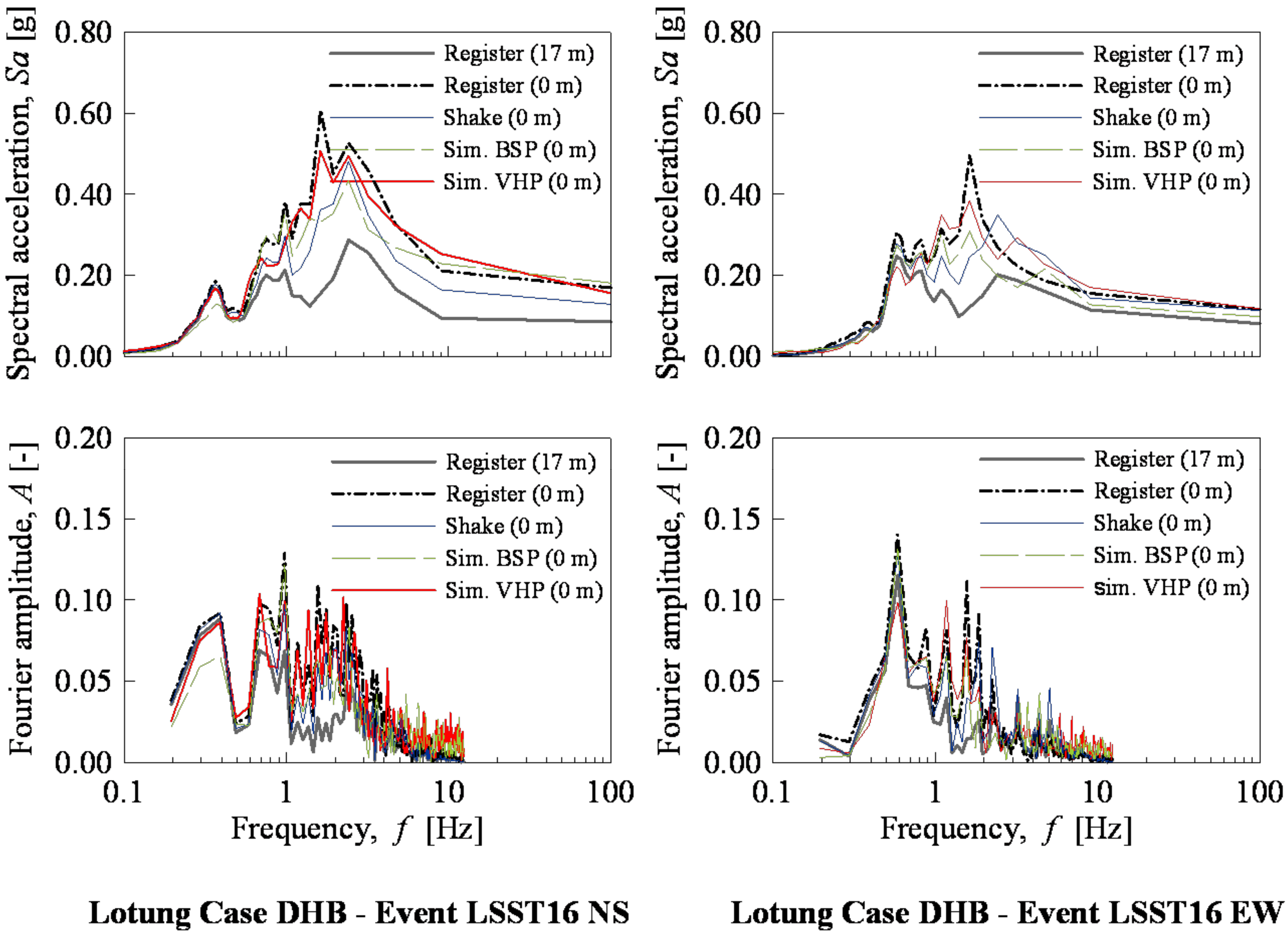
Lotung Case DHB - Event LSST07 NS

Lotung Case DHB - Event LSST07 EW

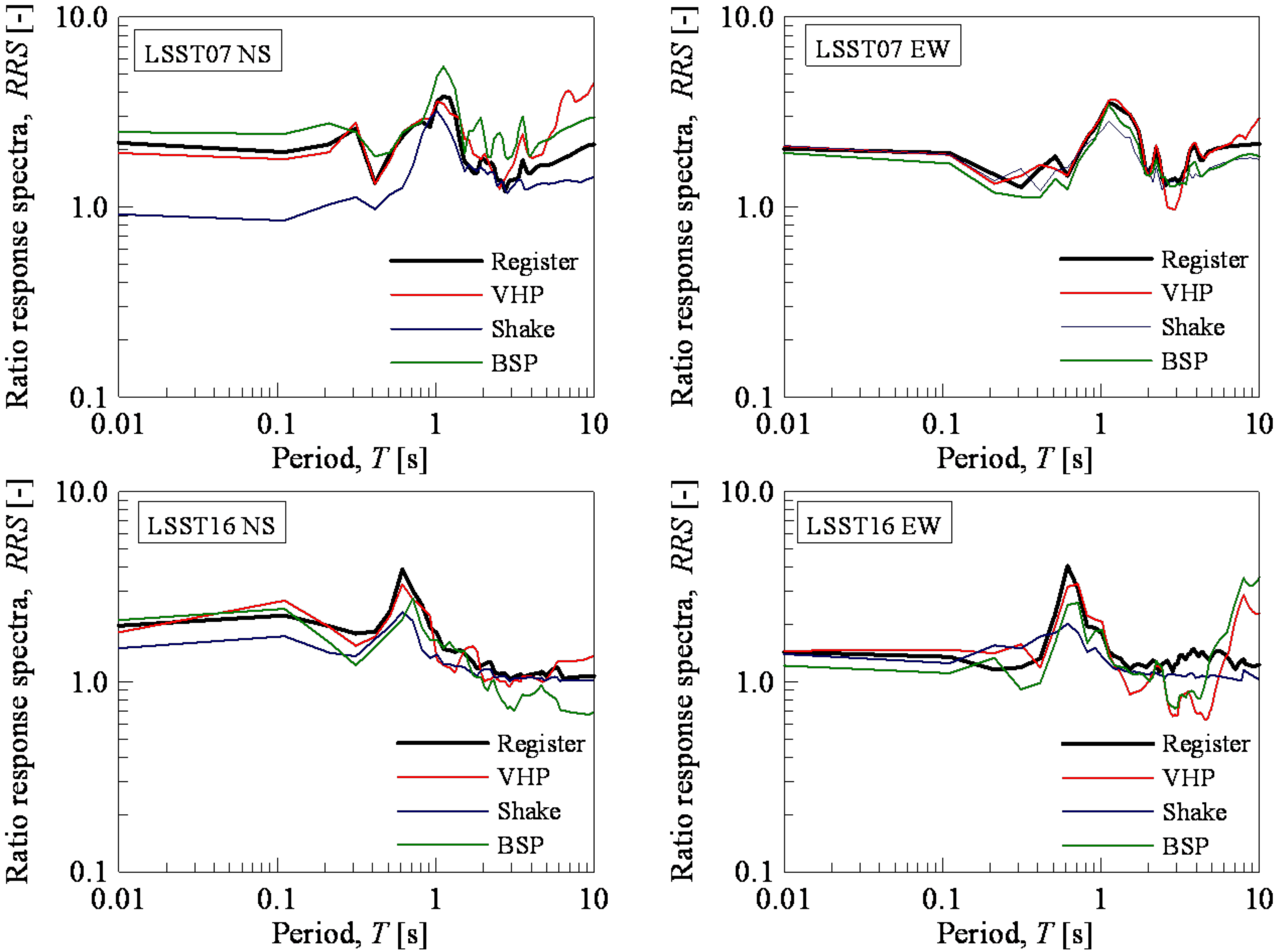
- Results LSST16



Site Response Using a Visco-hypoplastic model



Site Response Using a Visco-hypoplastic model

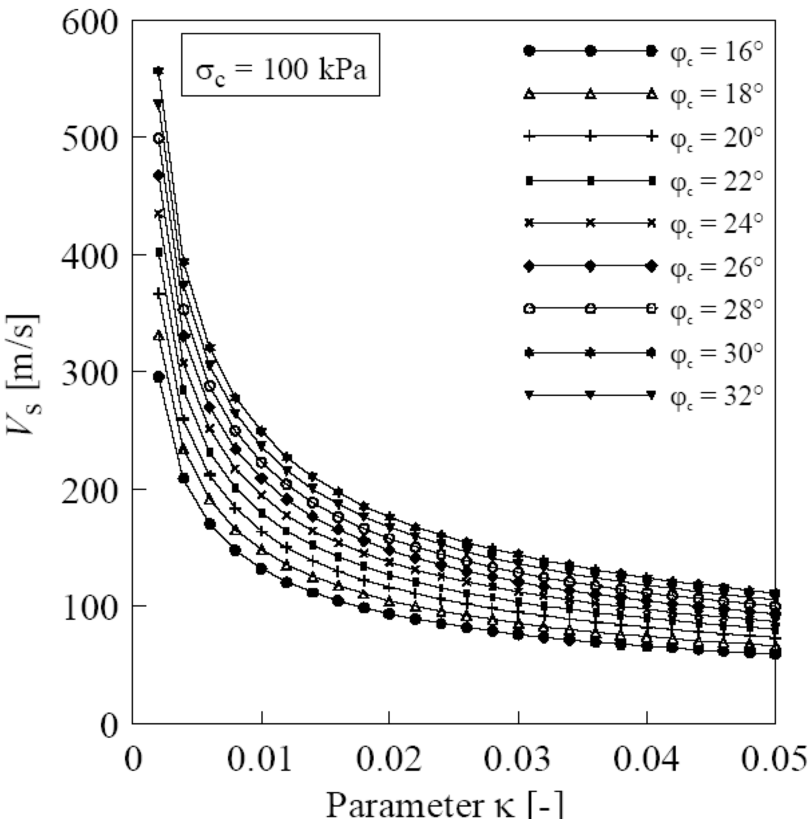


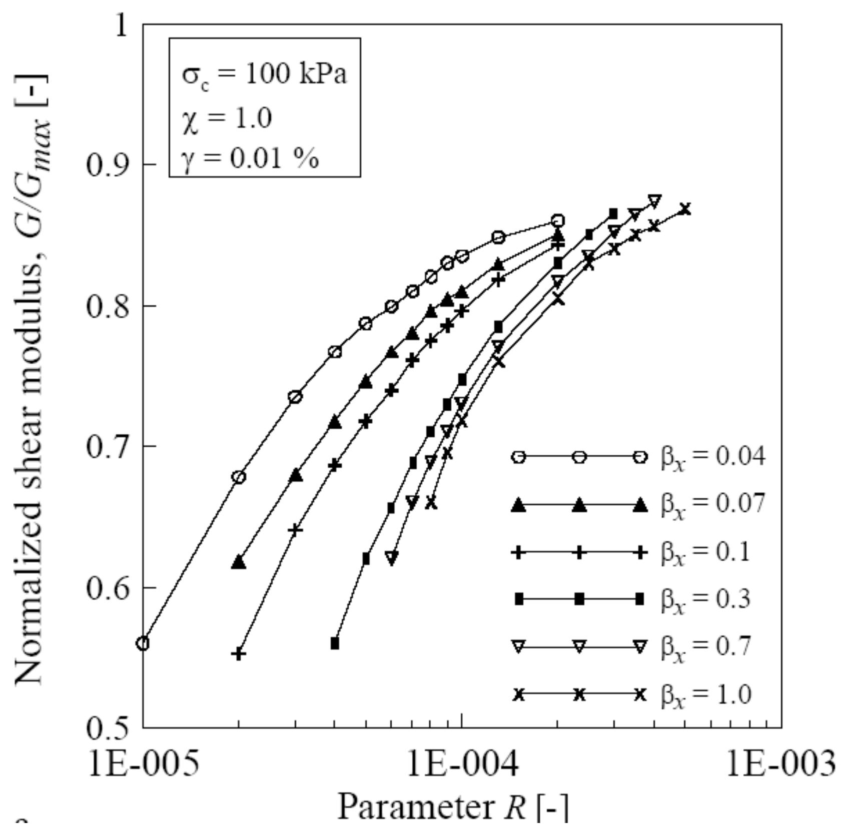
Uncertainty in Site Properties

Linear -equivalent characterization: → **Visco-hypoplastic parameters**

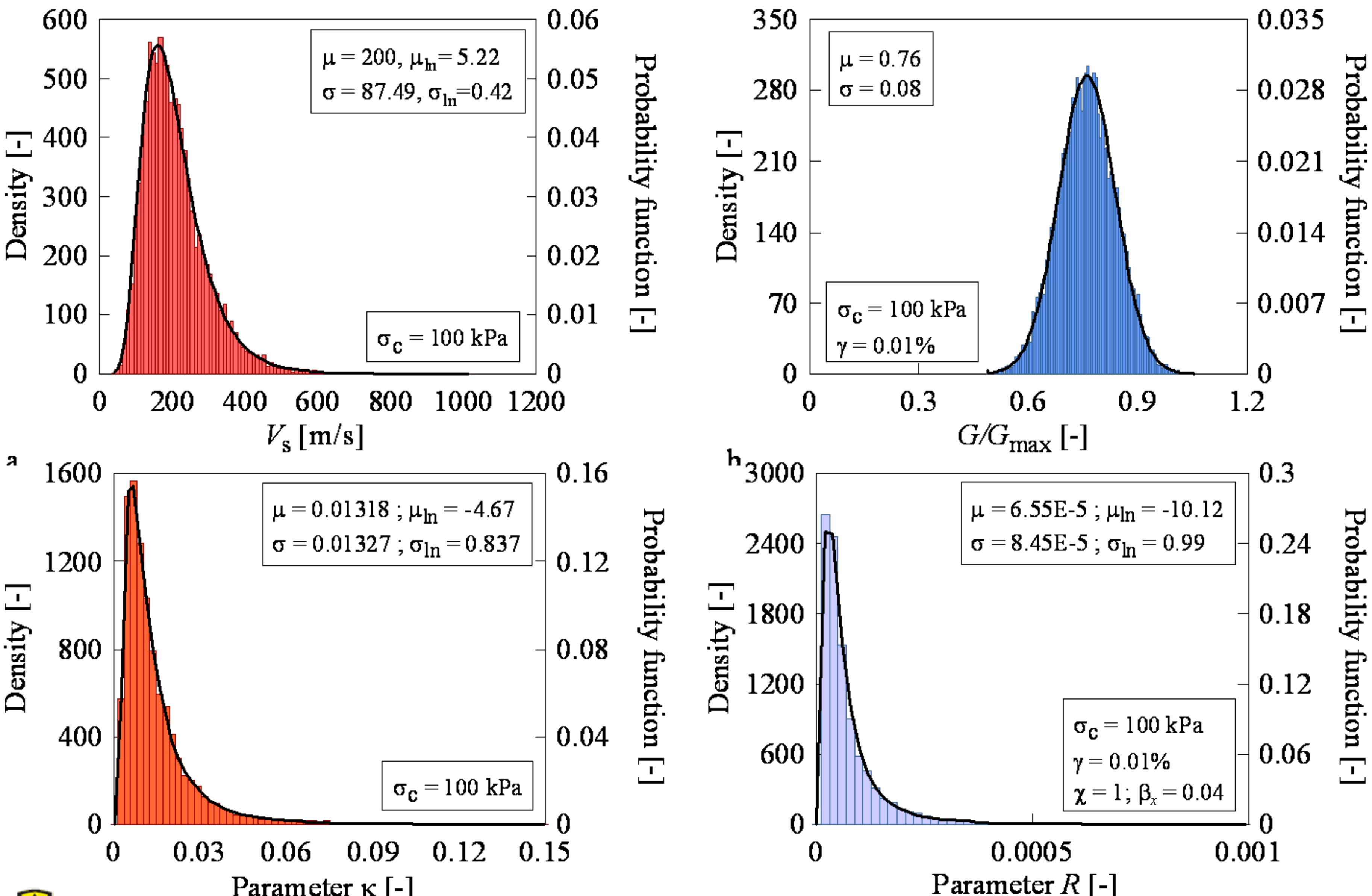
Shear wave velocity V_S → κ, φ_c

Dynamic curves G/G_{max} vs. γ, D vs. γ → R



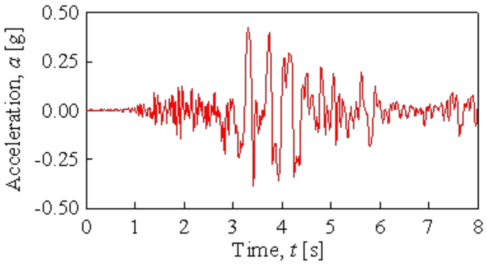


Uncertainty in Site Properties



Site profile 1: Uniform soil profile 50 m - soft soil

Input motion: Deterministic
Strong motion (PGA = 0.2 g)
Weak motion (PGA = 0.05 g)



Variability: Visco-hypoplastic soil parameters (κ, R)

Site Response: 1D – Soil column

Comp. Tool: ABAQUS

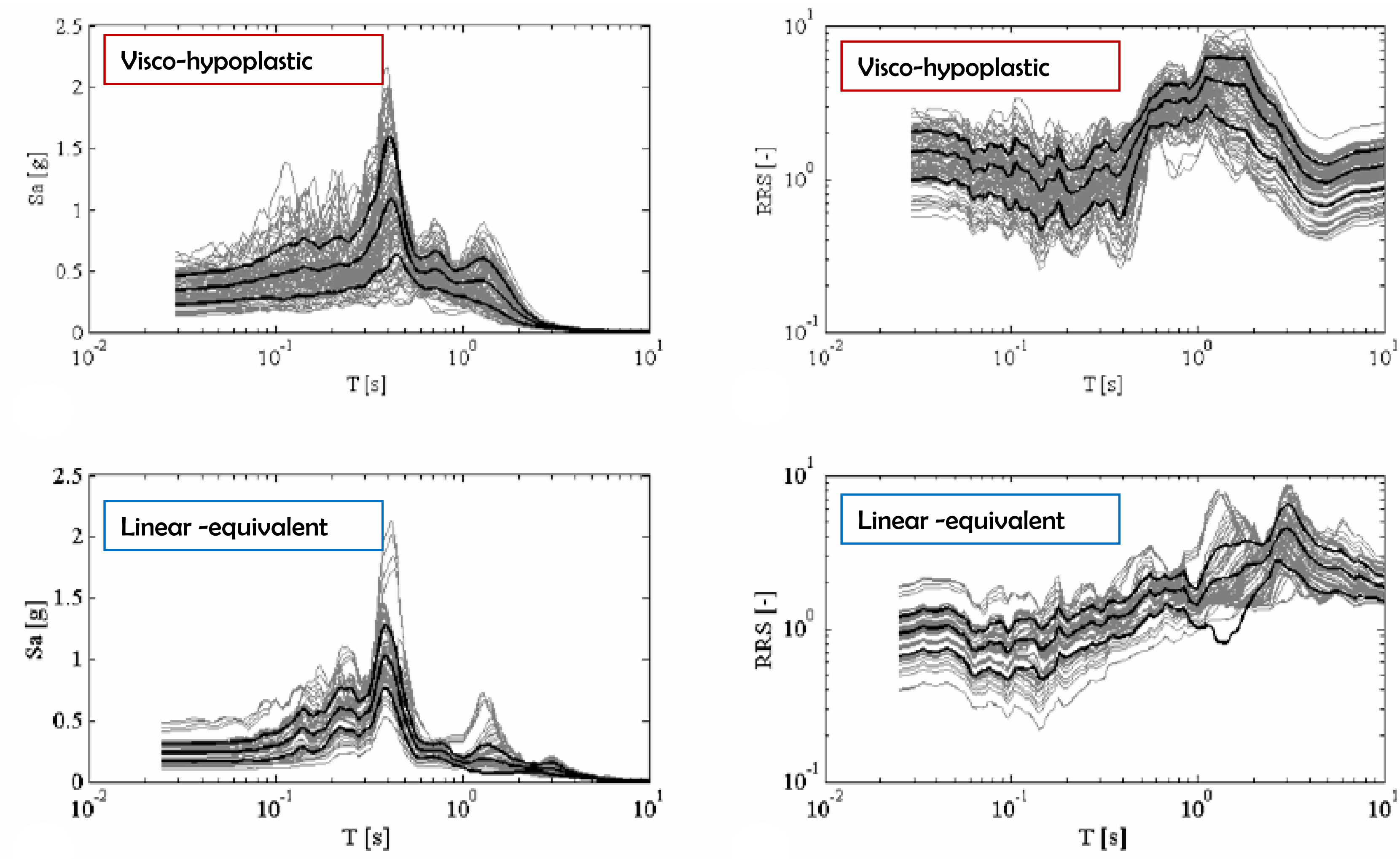
Methodology: Monte Carlo simulations

Comparison: Results from inear-equivalent approach

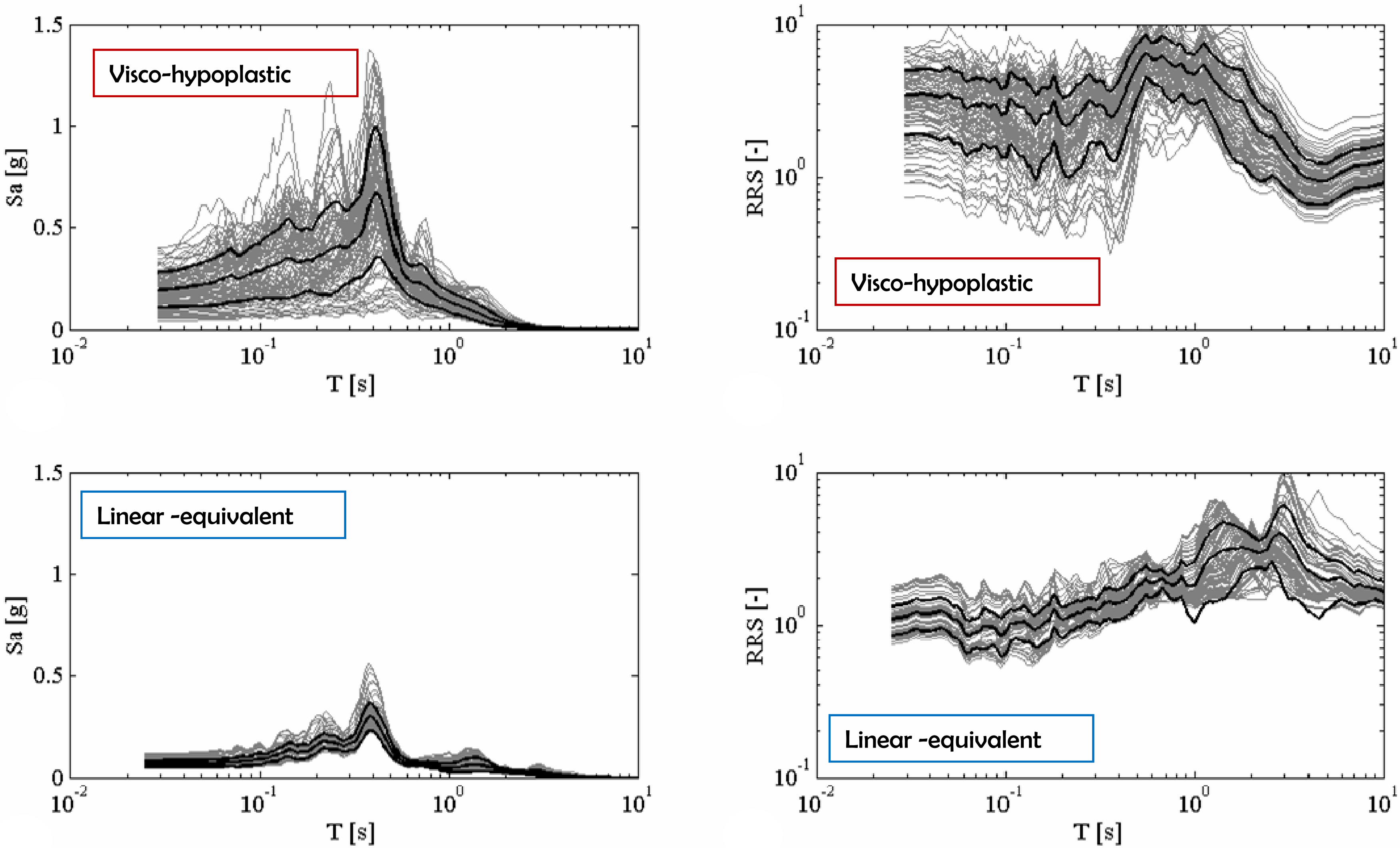
Uncertainty in Site Properties

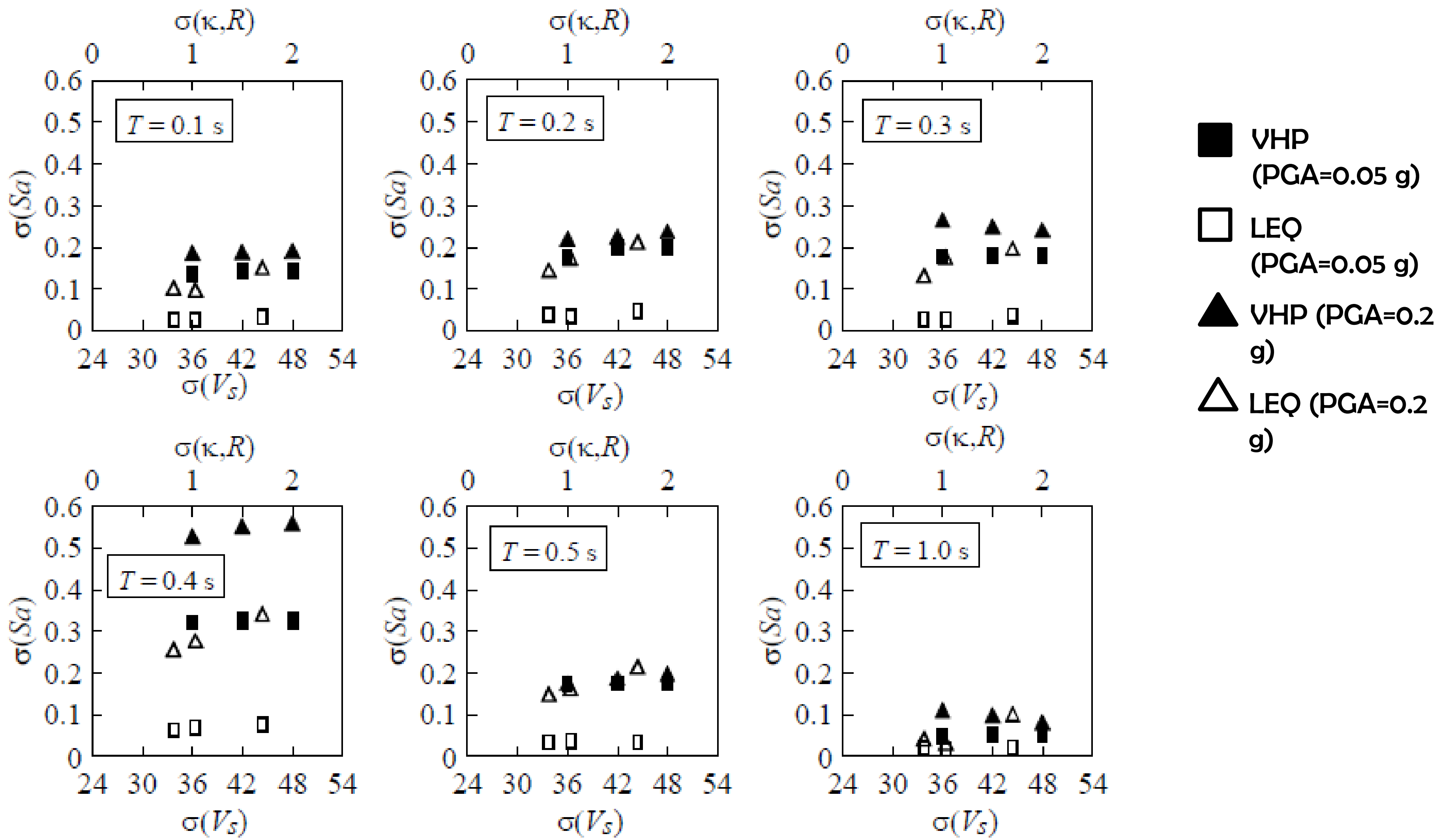
Results

PGA = 0.2 g (Strong motion)



PGA = 0.05 g (Weak motion)

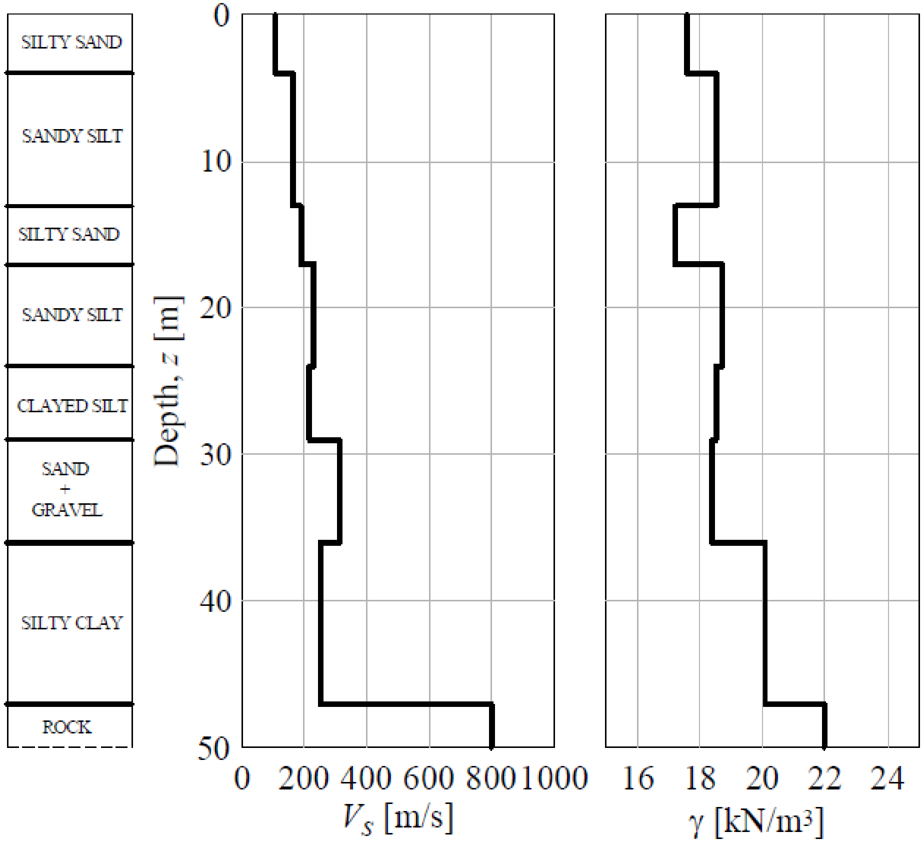


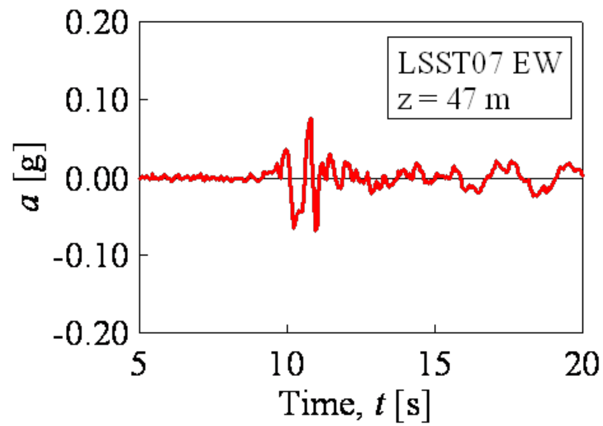


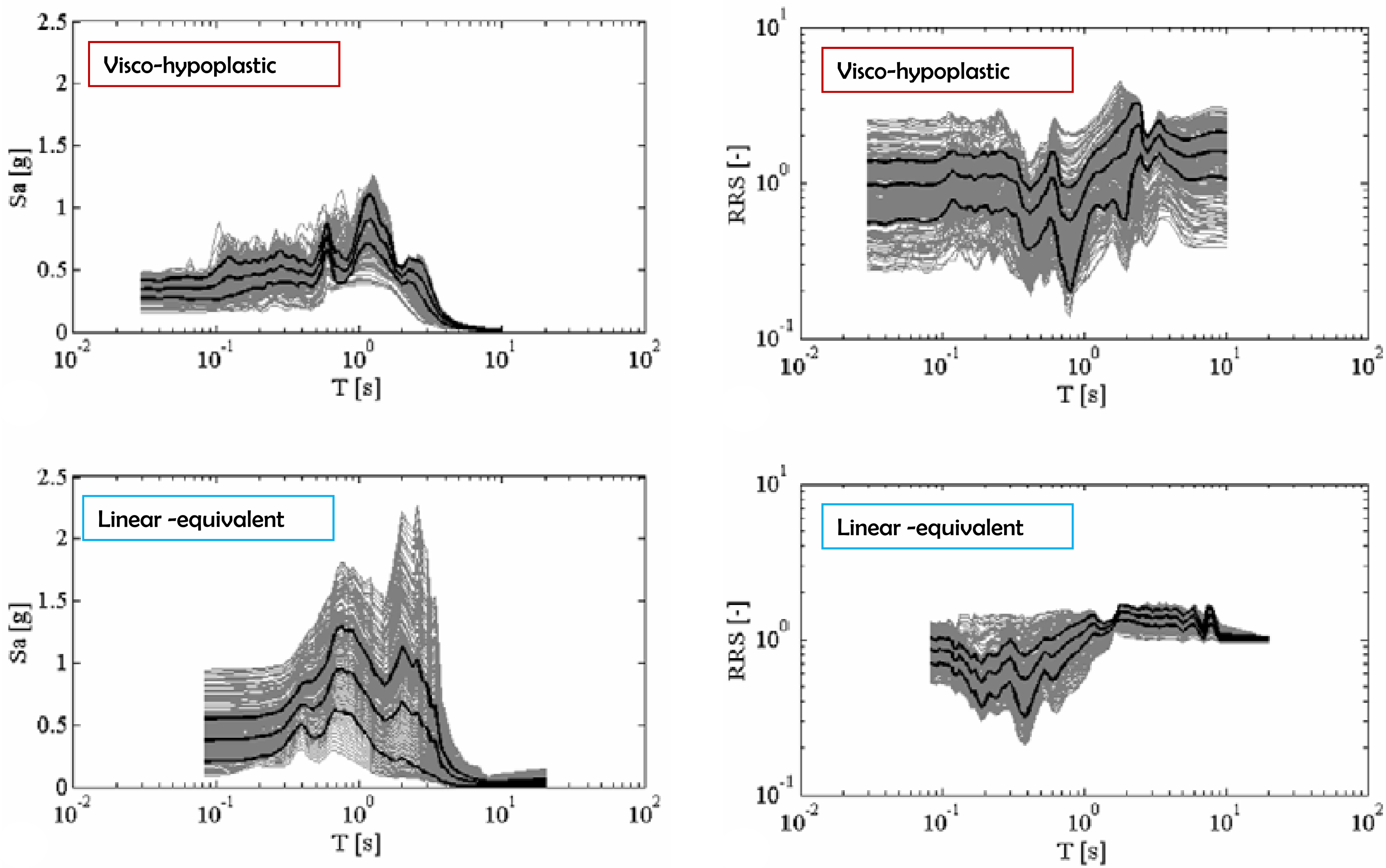
σ(κ,R)
0
1
2
0.6
0.5
0.4
0.3
0.2
0.1
0
σ(Sa)
T = 0.1 s
T = 0.2 s
T = 0.3 s
T = 0.4 s
T = 0.5 s
T = 1.0 s
24
30
36
42
48
54
σ(Vs)
VHP (PGA=0.05 g)
LEQ (PGA=0.05 g)
VHP (PGA=0.2 g)
LEQ (PGA=0.2 g)

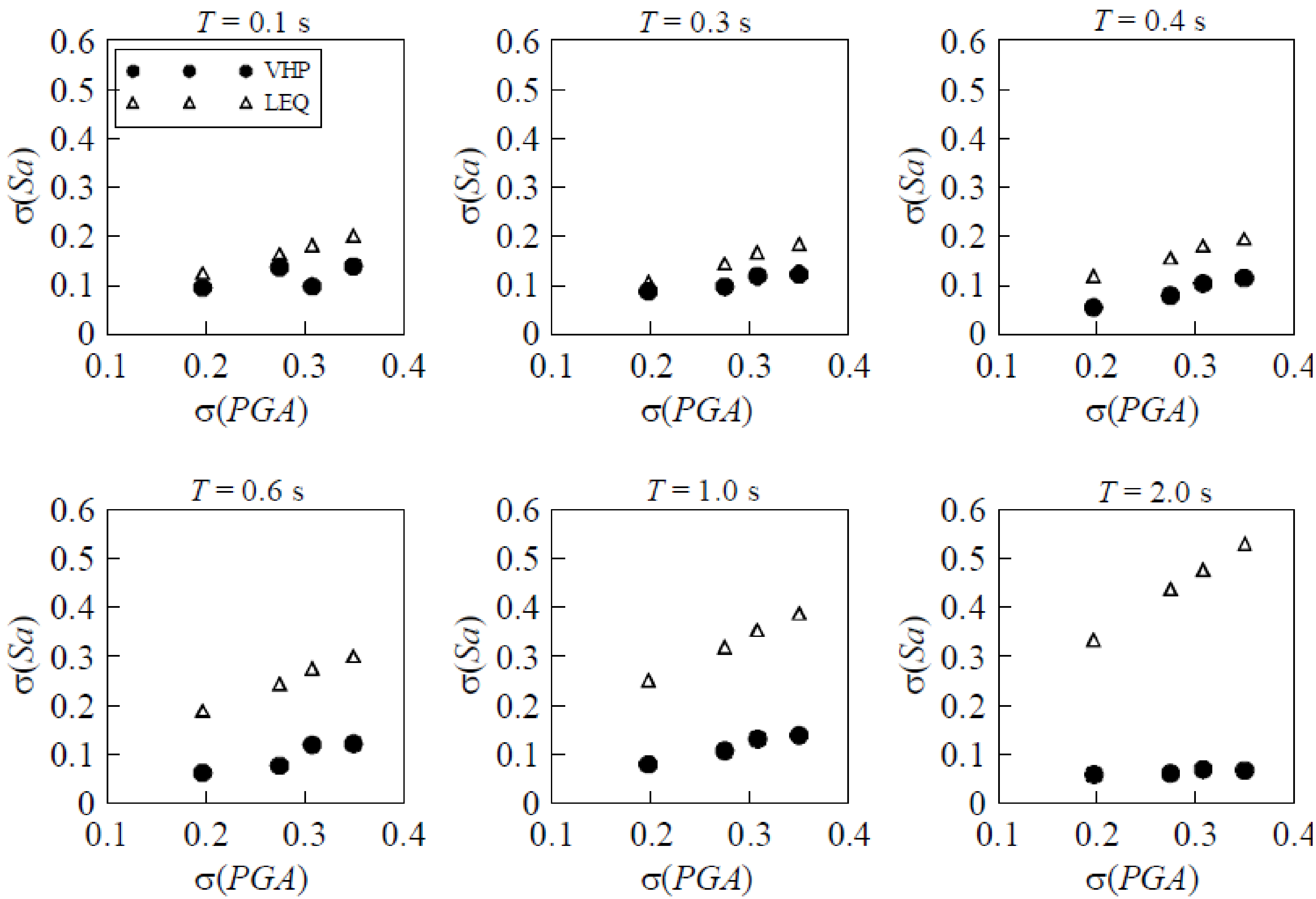
Site profile 2 : Lotung array, LSST, Taiwan (EPRI, 2003)

Variability: Input motion (PGA Log-normally distributed)



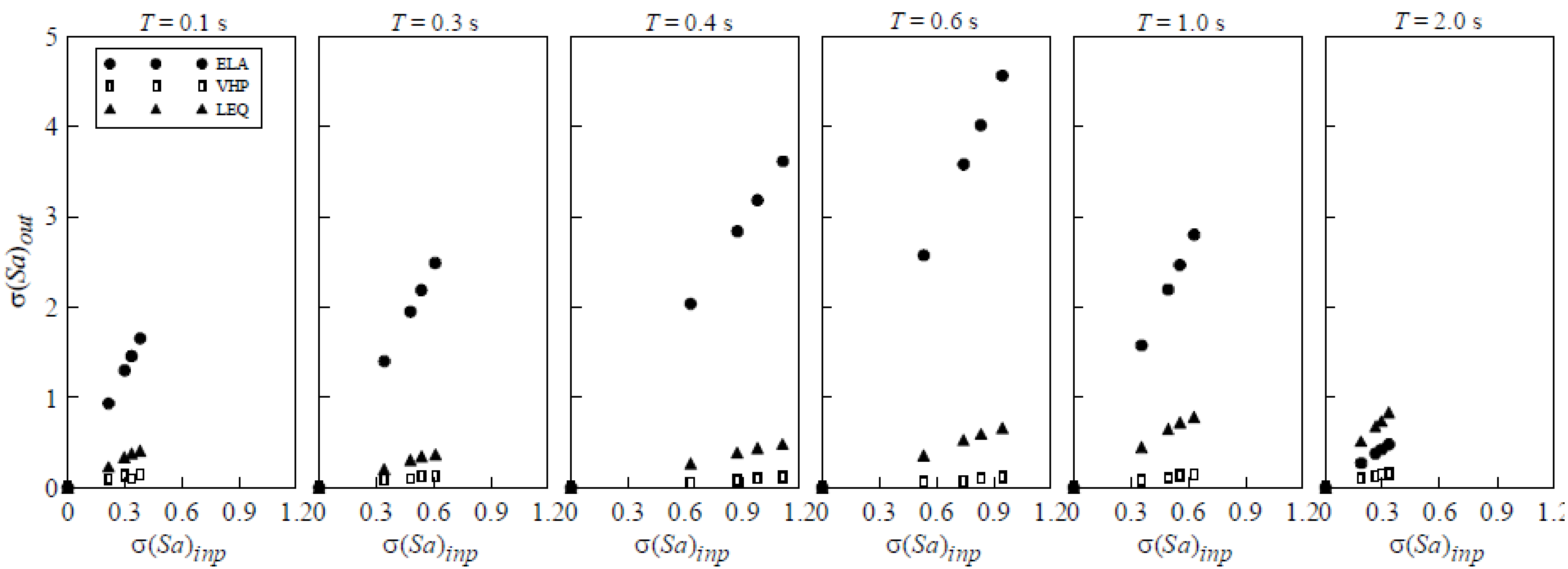



Visco-hypoplastic
Sa [g]
T [s]
Visco-hypoplastic
RRS [-]
T [s]
Linear -equivalent
Sa [g]
T [s]
Linear -equivalent
RRS [-]
T [s]



T = 0.1 s
T = 0.3 s
T = 0.4 s
T = 0.6 s
T = 1.0 s
T = 2.0 s
VHP
LEQ
σ(Sa)
σ(PGA)
0 0.1 0.2 0.3 0.4 0.5 0.6
0.1 0.2 0.3 0.4

Uncertainty in the Input Ground Motion
Results



Conclusions

- Nonlinear models reduce the expected uncertainty of ground motions
- Output variability is controlled by the variability of the input motion
- For the visco-hypoplastic model, overamplification is observed when subjected to low intensities. For higher intensities, the median results from the equivalent linear and visco-hypoplastic models are comparable.
- For high intensities the visco-hypoplastic model predicts incursions into plastic regions. This episodic yielding results in a cap in output spectral accelerations which in turn result in lower output variability when compared to an equivalent linear model.
- Output uncertainty in site response analyses is smaller when fully non-linear analyses are conducted as opposed to equivalent linear analyses.

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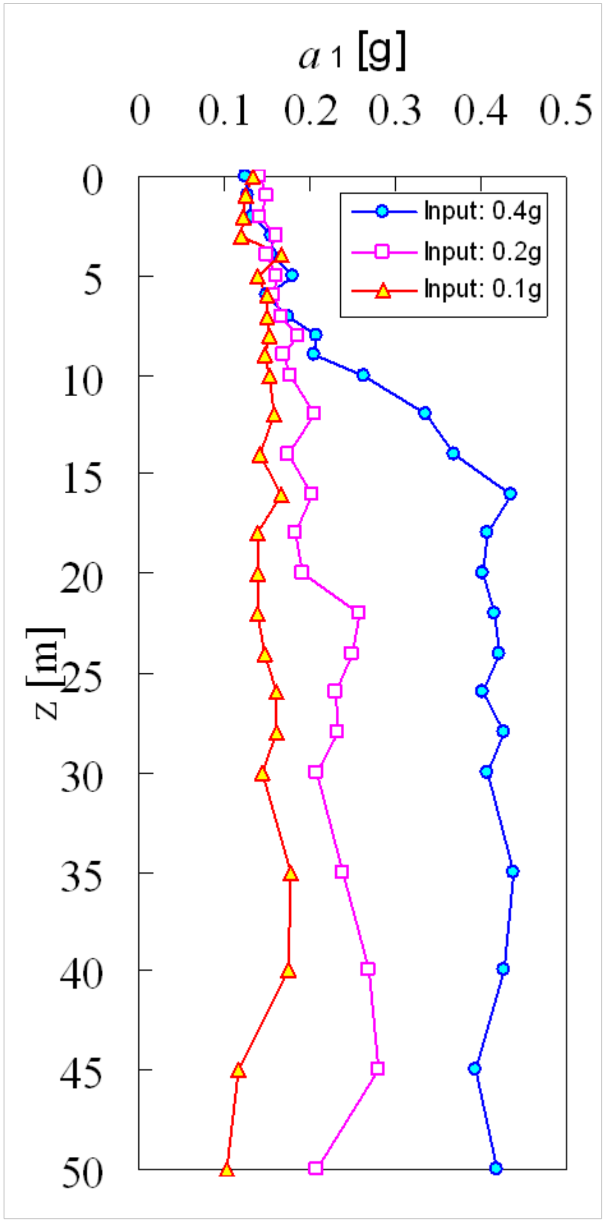
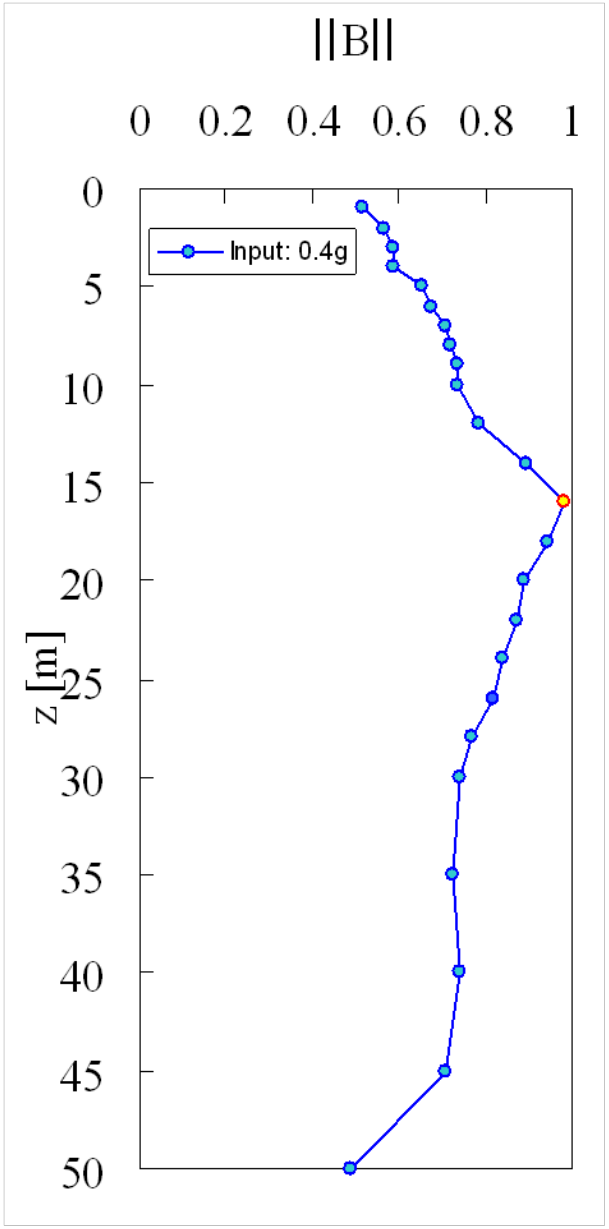
- Department of Civil and Environmental Engineering – Washington State University
- COLCIENCIAS

Thanks!



a_1 [g]
0 0.1 0.2 0.3 0.4 0.5
Input: 0.4g
Input: 0.2g
Input: 0.1g
z [m]
0 5 10 15 20 25 30 35 40 45 50



||B||
0 0.2 0.4 0.6 0.8 1
Input: 0.4g
z [m]
0 5 10 15 20 25 30 35 40 45 50

- G_{max} is controlled by:

Visco-hypoplastic parameters: φ_c, κ

$$c_1 = \sqrt{\frac{(k_1 + k_2) f_b \mathsf{L}_{1212} - (T_{22} - T_{11}) \mathsf{L}_{12kl} D_{kl}^{vis}}{\rho}} \quad \textbf{for} \quad h_{12} D_{12} > 0$$

$$c_2 = \sqrt{\frac{(k_1 + k_3) f_b \mathsf{L}_{1212} - (T_{22} - T_{11}) \mathsf{L}_{12kl} D_{kl}^{vis}}{\rho}} \quad \textbf{for} \quad h_{12} D_{12} < 0$$

$$k_1 = \rho^{\chi} m_T + \left(1 - \rho^{\chi}\right) m_R$$

$$k_2 = \rho^{\chi} \left(1 - m_T\right)$$

$$k_3 = \rho^{\chi} (m_R - m_T)$$

$$f_b \operatorname{tr}(\mathbf{T}) = -\frac{\operatorname{tr}(\mathbf{T})}{\left(1 + a^2/3\right)\kappa} \qquad a = \frac{\sqrt{3}(3 - \sin\varphi_c)}{2\sqrt{2}\sin\varphi_c}$$

Hypoplastic parameters: φ_c, h_s, n, e_{i0}, e_{c0}, e_{d0}, β

$$f_b = \left(\frac{e_{i0}}{e_{c0}}\right)^{\beta} \frac{h_s}{n} \frac{\mathbf{1} + e_i}{e_i} \left(-\frac{tr\mathbf{T}}{h_s}\right)^{1-n} \left[3 + a^2 - a\sqrt{3}\left(\frac{e_{io} - e_{d0}}{e_{c0} - e_{d0}}\right)\right]^{-1}$$

Predicted dynamic curves using visco-hypoplasticity for the Bay Mud