Validating nonlinear site response prediction methodologies for SCEC broadband ground motion simulations

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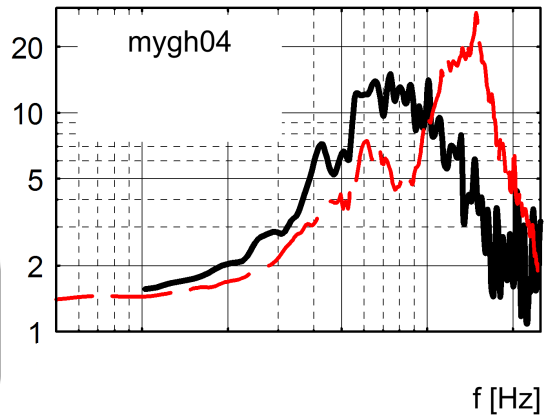Georgia Institute of Technology, Atlanta, GA

SCEC Ground Motion Validation Workshop
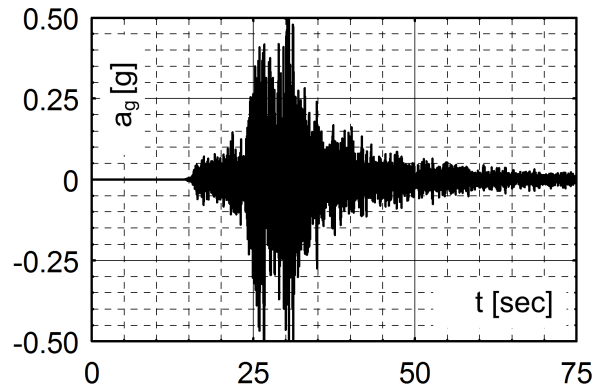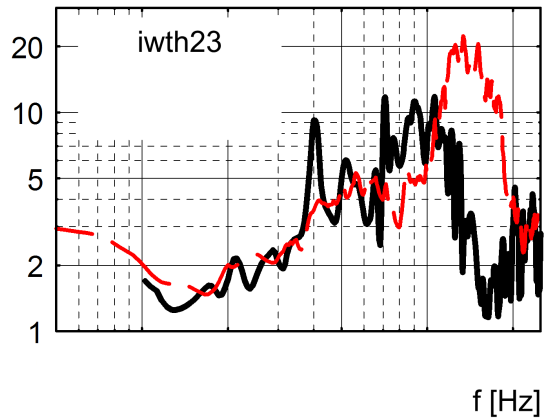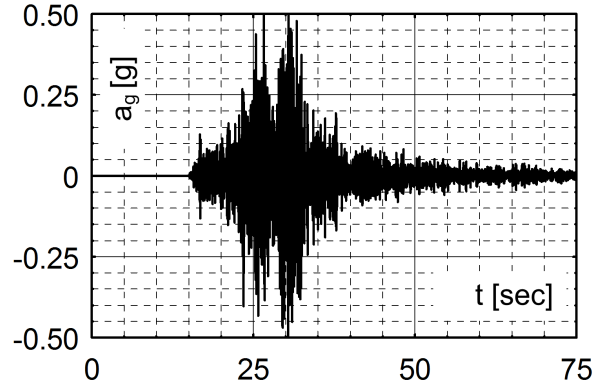
USC April 3, 2013
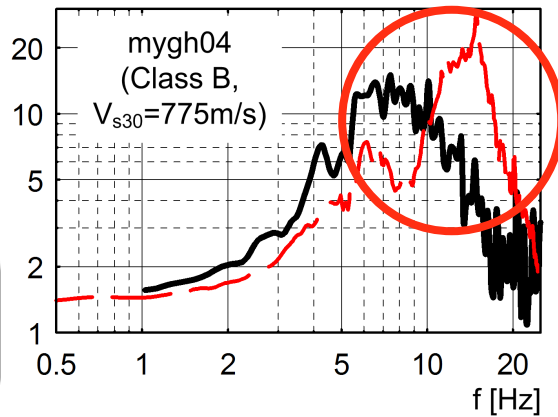
Evidence of Nonlinear Site Response

Site amplification

mygh04

20

10

5

2

1

f [Hz]

Mainshock surface record

0.50

0.25

a_g [g]

0

-0.25

-0.50

0   25   50   75

t [sec]

iwth23

20

10

5

2

1

f [Hz]

0.50

0.25
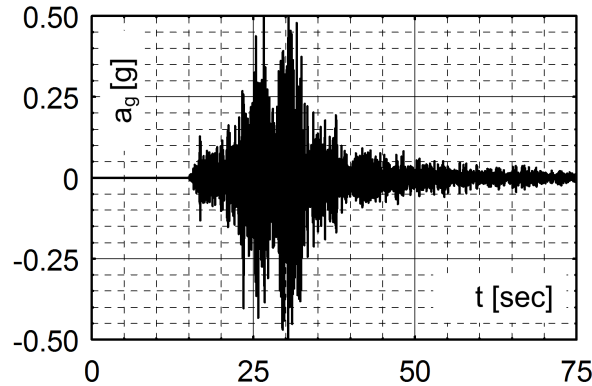
a_g [g]

0

-0.25

-0.50

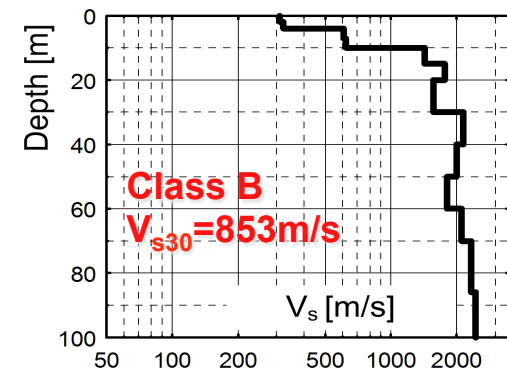0   25   50   75

t [sec]

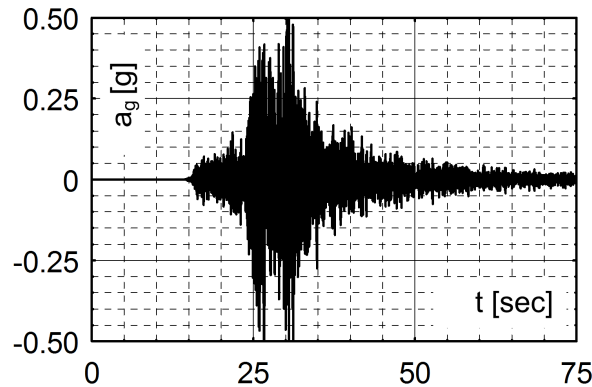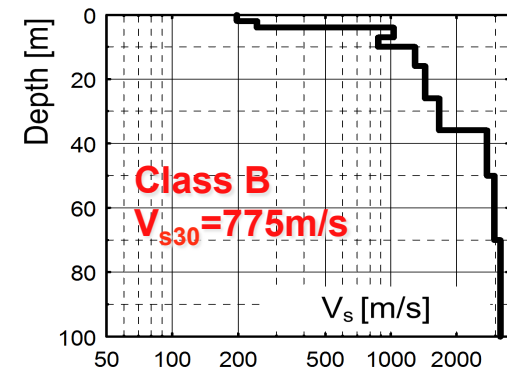# Nonlinear site effects = f (V_{s30}, PGA_{RO}, ?)

Site amplification

Mainshock surface record

Shear wave velocity

mygh04
(Class B,
V_{s30}=775m/s)

Class B
V_{s30}=775m/s

iwth23
(Class B,
V_{s30}=853m/s)

Class B
V_{s30}=853m/s
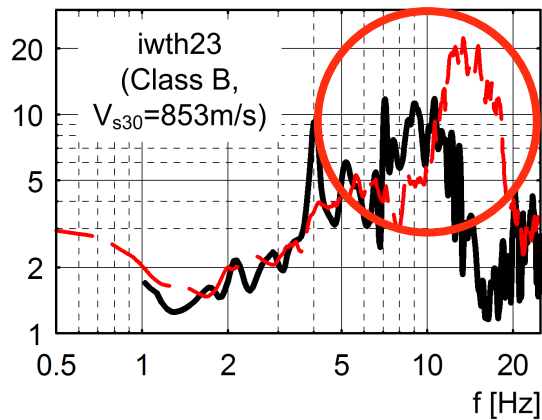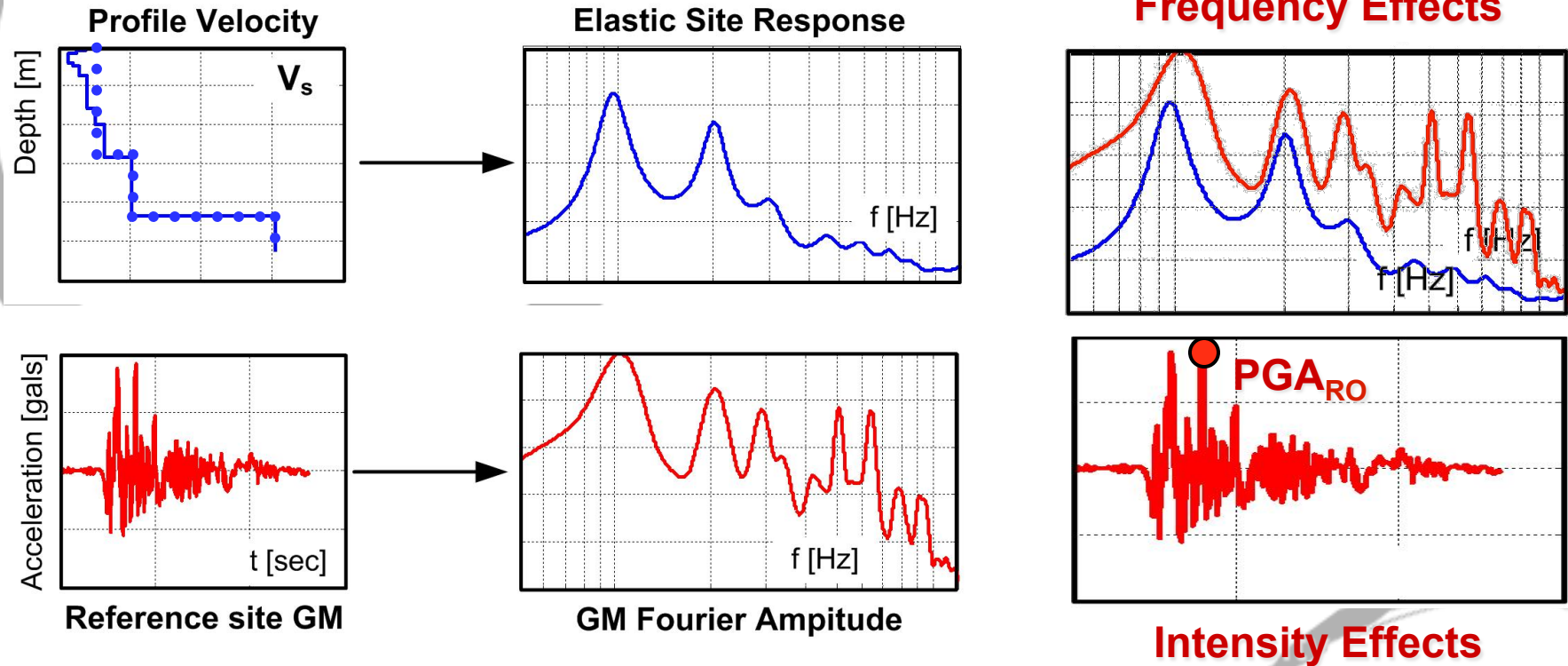
Nonlinear site amplification f (frequency)

Parameterizing nonlinear response: Single Station

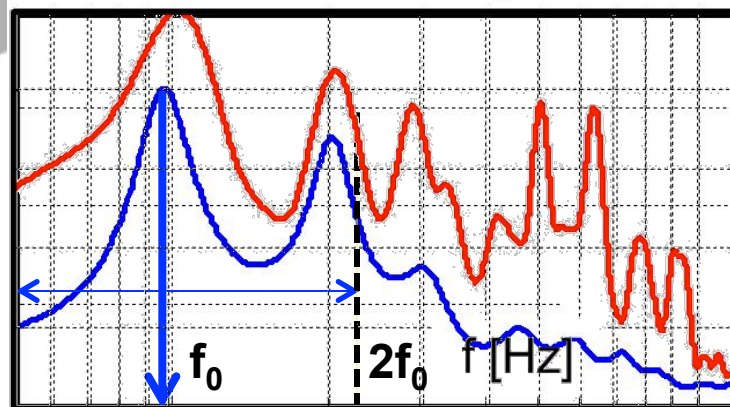$f_{GM} \approx f_{soil}$: Incident energy "trapped" in the soil

Intensity (PGA_{RO}) = Is it strong enough to cause nonlinear effects?

Parameterizing frequency effects
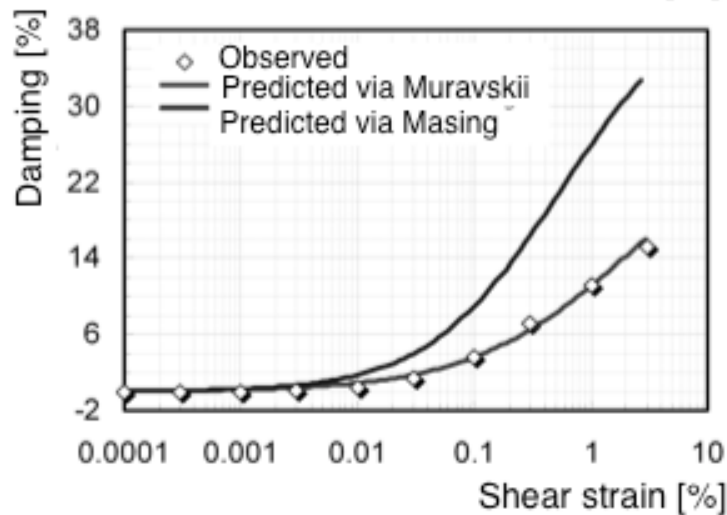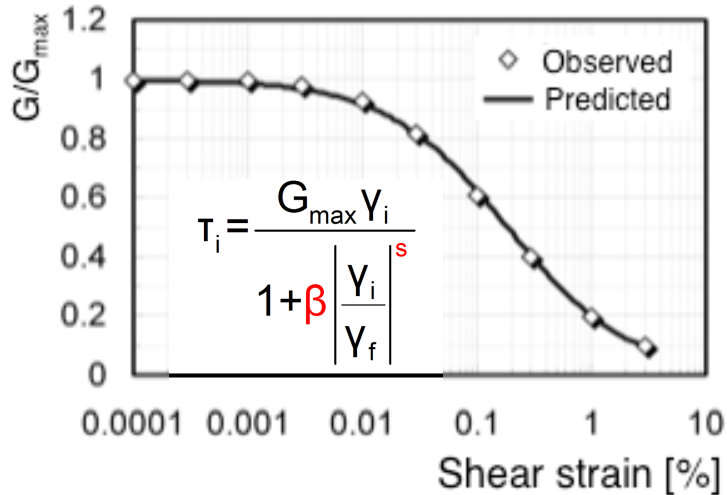
a. Frequency Index (I_f): Site Specific

$$I_f = \frac{2 \sum_{i=1}^{N} TF_i^{soil} \times FAS_i^{GM}}{\sum_{i=1}^{N} TF_i^{soil} TF_i^{soil} + \sum_{i=1}^{N} FAS_i^{GM} FAS_i^{GM}}$$
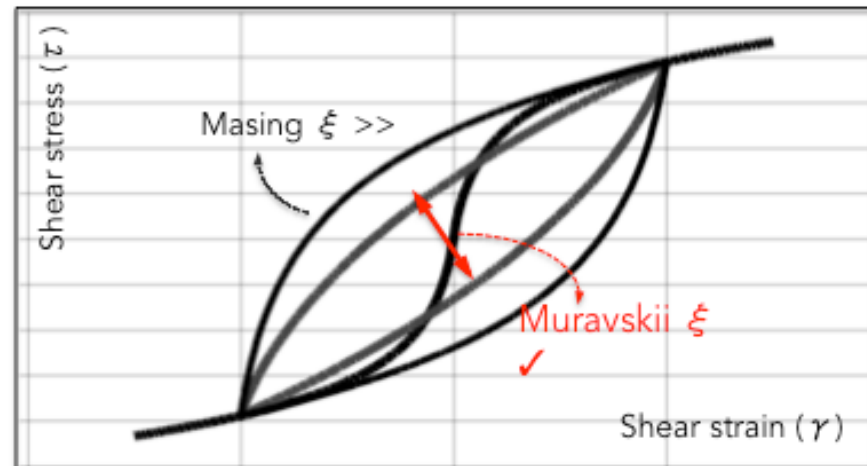

Resonance (Frequency) Effects

Nonlinear Soil Model (Li & Assimaki, 2009)

Matasovic & Vucetic (1995)

$$\tau_i = \frac{G_{max}\gamma_i}{1+\beta\left|\dfrac{\gamma_i}{\gamma_f}\right|^s}$$

Modified Muravskii (2005)

1. U-R scaled and translated replicas of backbone

2.2 x {NL parameters} matching G/G_{max}, (ξ)

Realistic damping predictions

Same input parameters as equivalent linear

Automatic calibration using genetic algorithms
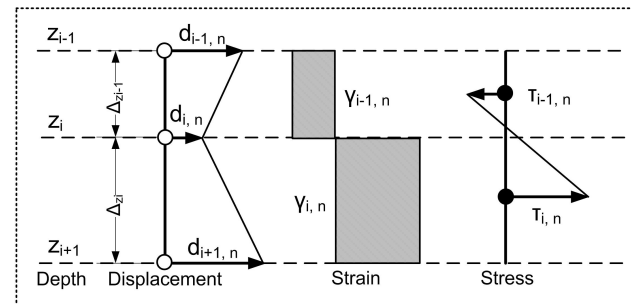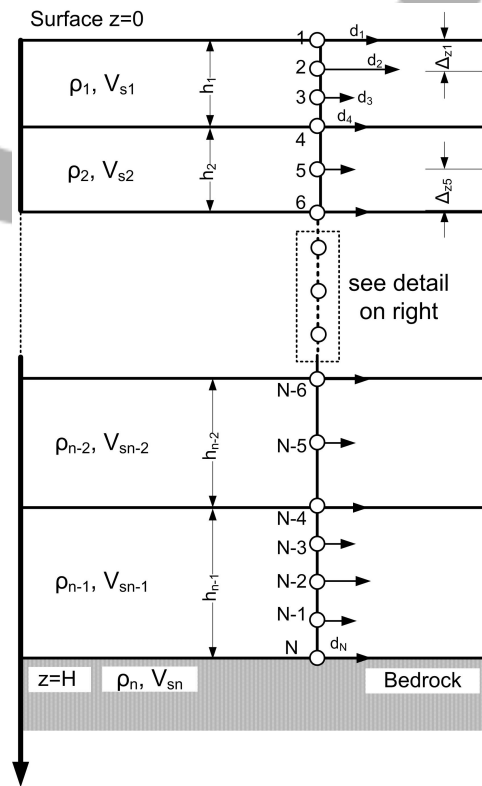
Validated via downhole array recordings

Nonlinear ground response analyses
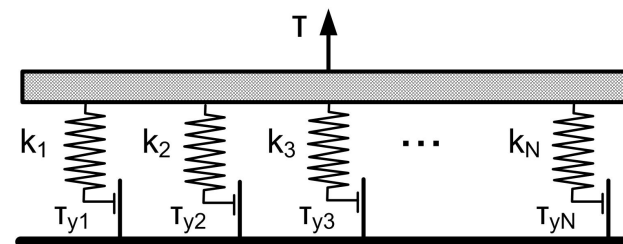
(Validated synthetics - downhole array strong records)

Unload-Reload rules: Modified Muravskii (2005)

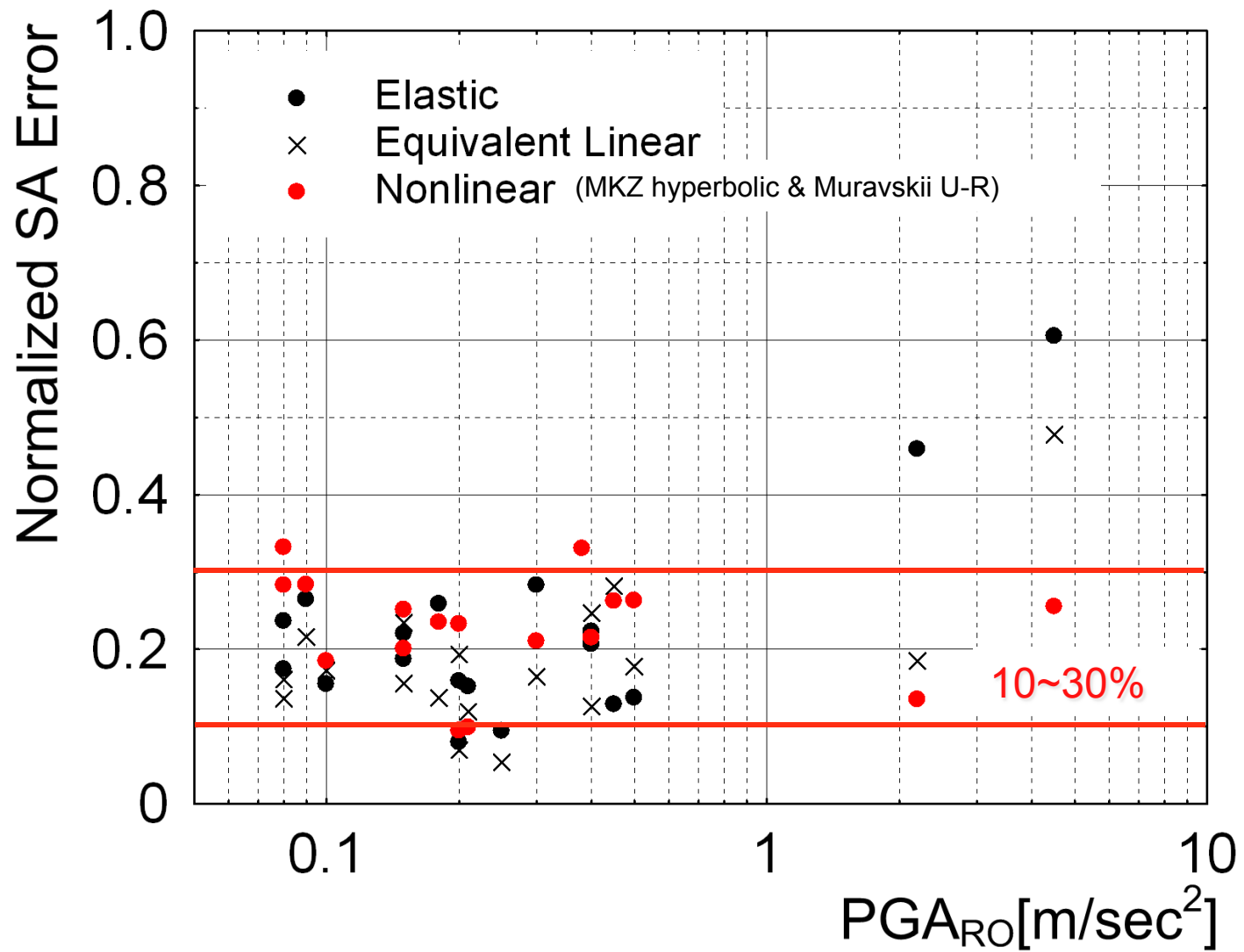**Small-stain damping (ξ):** SLS in parallel (Liu & Archuleta, 2006)

Numerical formulation: Finite differences, PML boundary conditions
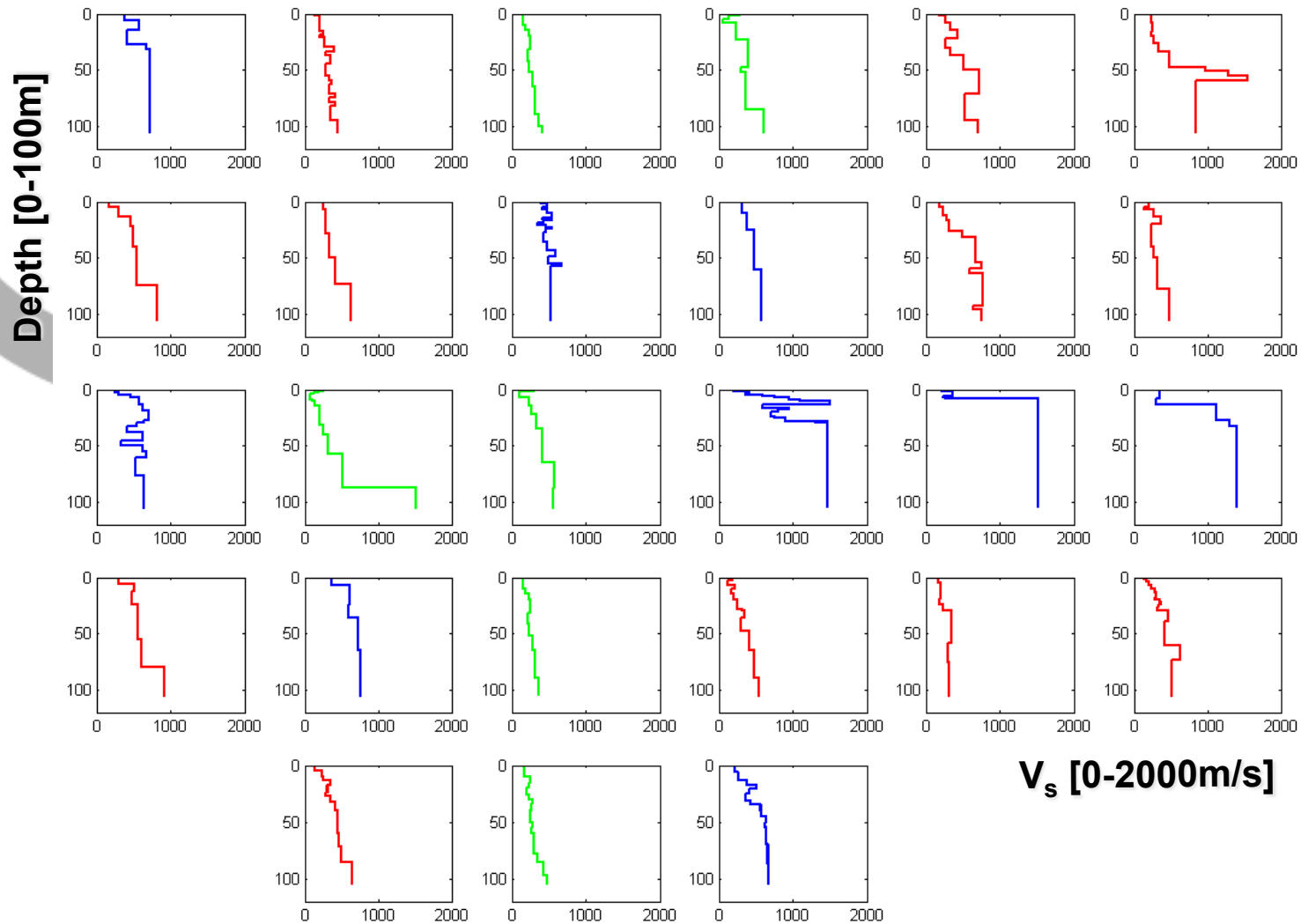

**Elastoplastic springs in parallel
Iwan (1967)**

Validation for SC downhole array recordings

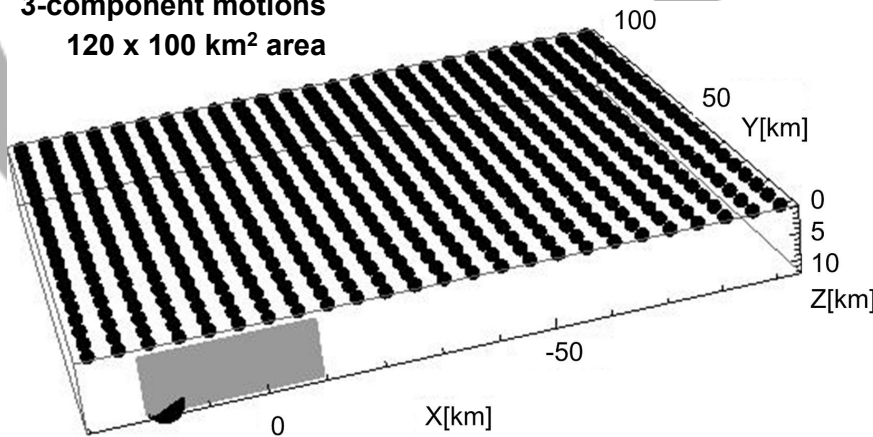# Site-Specific Synthetics @ SC Strong Motion Stations

27 Downhole arrays: 9 Class C, 12 Class D & 6 Class E

Depth [0-100m]

V_s [0-2000m/s]
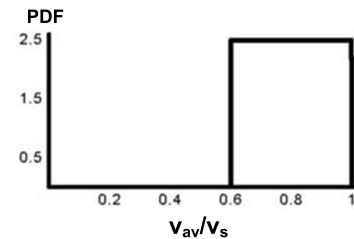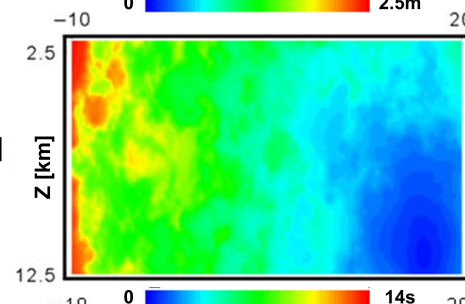
Broadband ground motion simulations
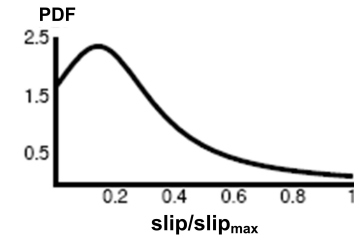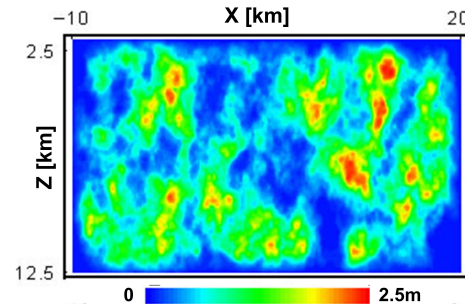## (Hybrid low/high frequency method w/ correlated random source parameters: Liu et al, 2006)
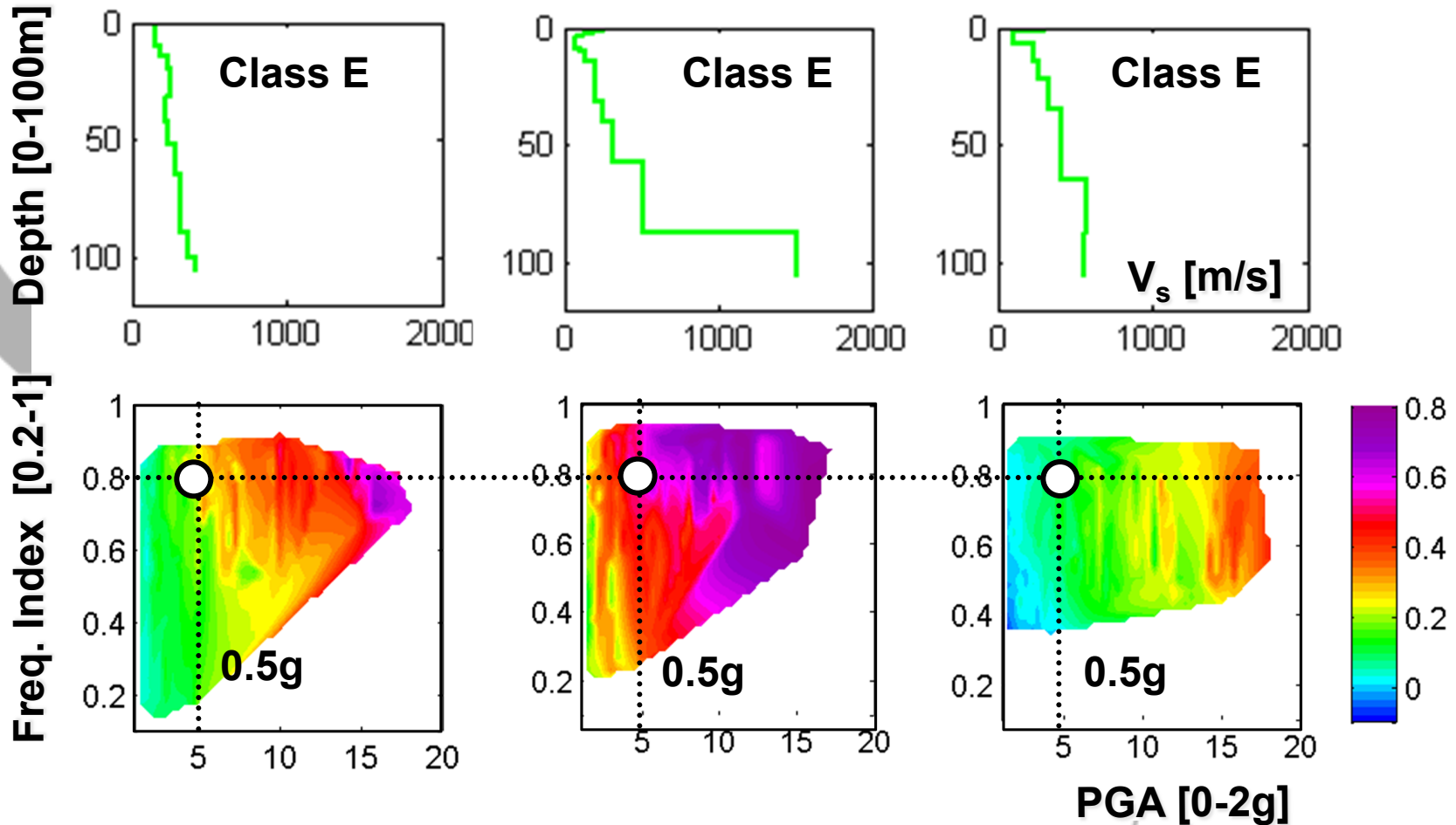
600 stations
3-component motions
120 x 100 km² area

EARTHQUAKE SCENARIA
multiple crustal velocity models (1D)
Strike-slip fault rupture mechanism
2 fault geometries (2.5km, 6km depth)
6 magnitudes (M = 3.5, 4, 5, 6, 6.5, 7)
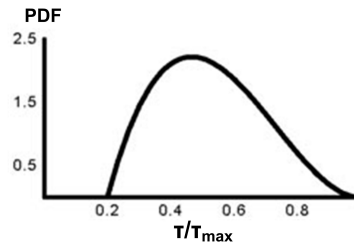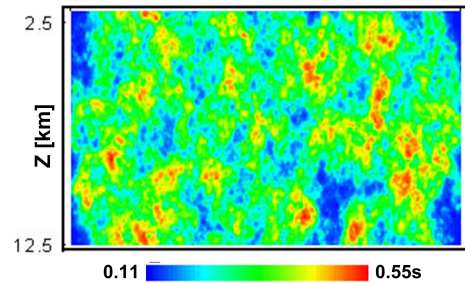
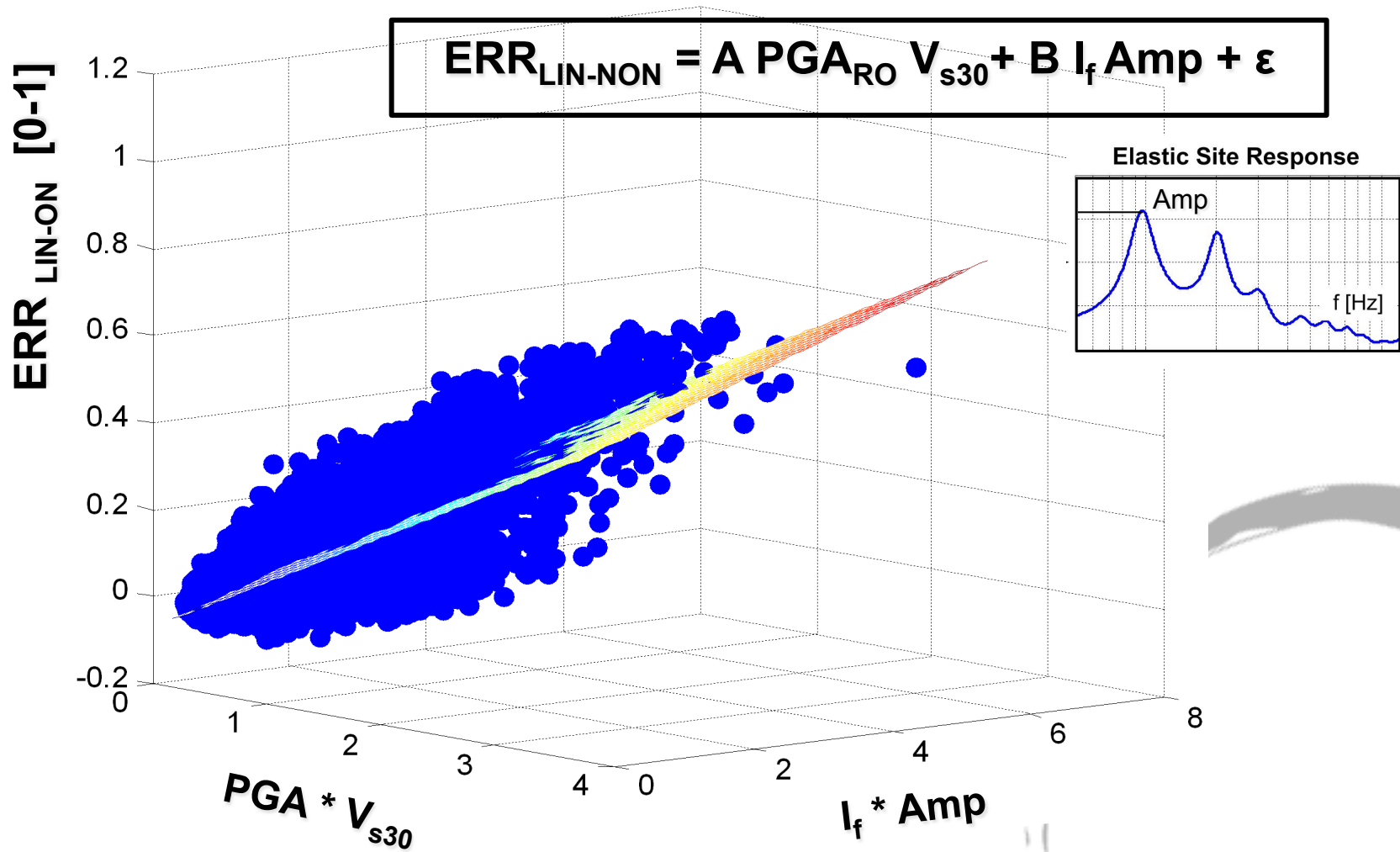# Nonlinear site response: Example for site class E

Severity of nonlinear response ≍ **Linear – Nonlinear Prediction Divergence**

Nonlinear effects = f (V_{s30}, V_{s30}/V_{s_RO}, ξ)

$$ERR_{LIN-NON} = A\ PGA_{RO}\ V_{s30} + B\ I_f\ Amp + \varepsilon$$

Elastic Site Response

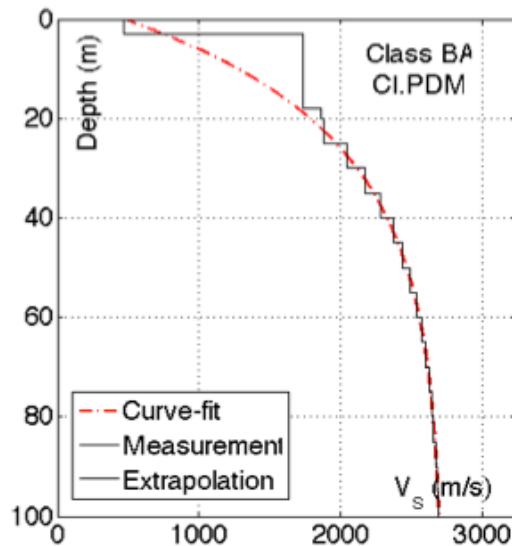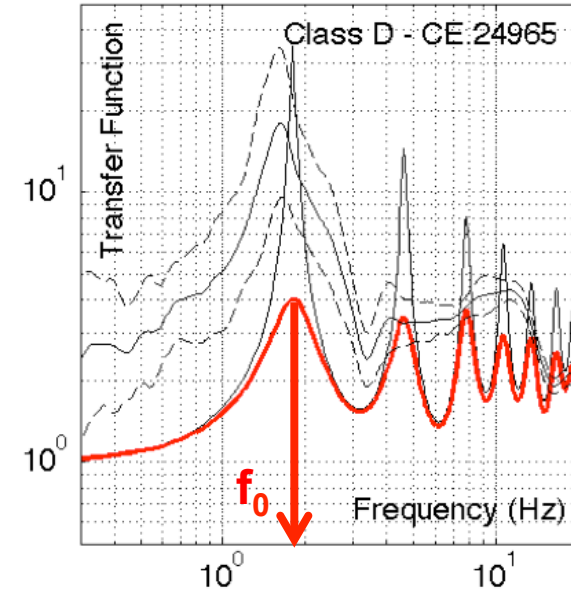(Assimaki et al, 2008, 2010 & 2012)
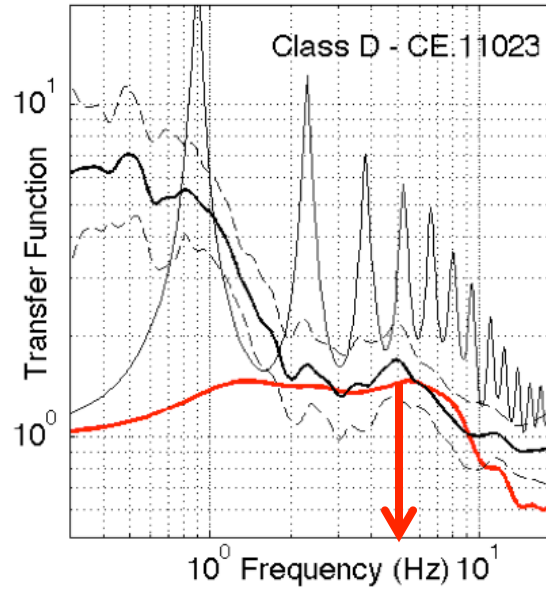
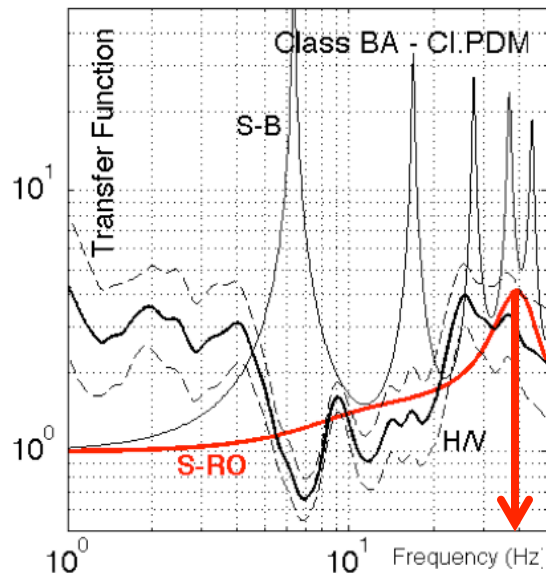# Parameterizing frequency effects

b. Frequency ratio (F_R): Regional Ground Motion Simulation

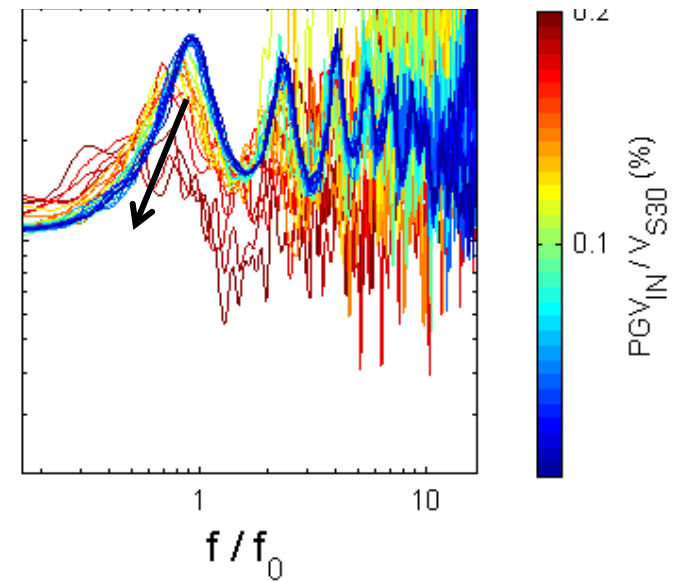$$F_R = \frac{f_C^{GM}}{f_0^{site}} = \frac{\sum_{i=1}^{N} f_i \times (FAS_i^{GM})^3}{f_0^{site} \times \sum_{i=1}^{N} f_i}$$
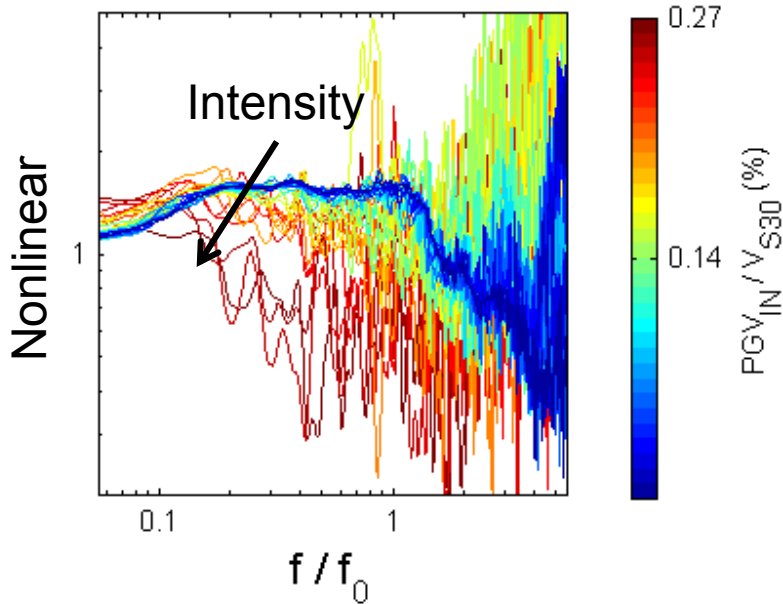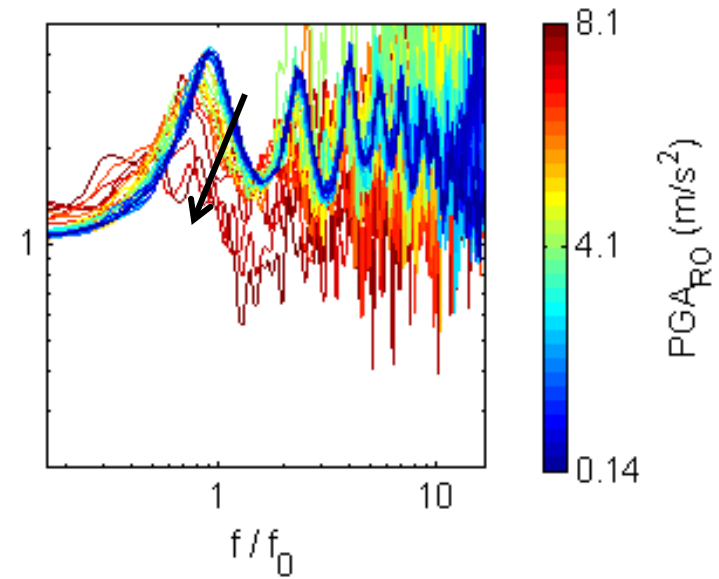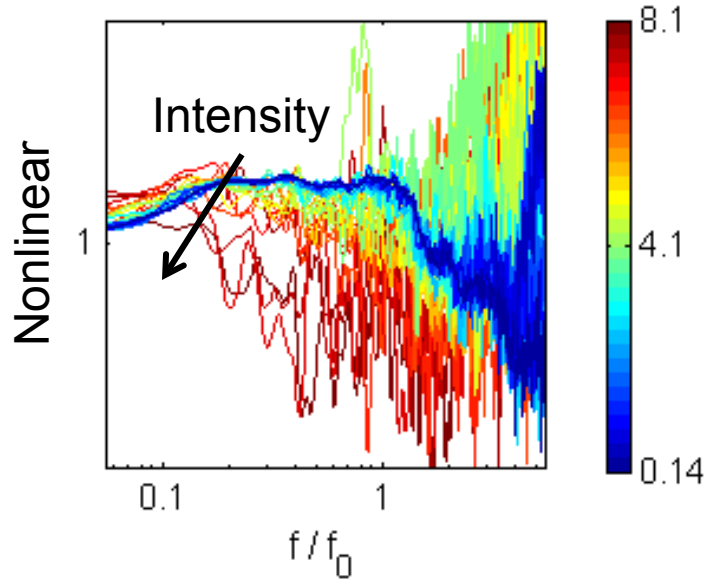
c. Harmonic Frequency ratio (F_H): Attenuation Relations - Hazard Maps

$$F_H = \frac{PGA}{PGV \times 2\pi f_0}$$
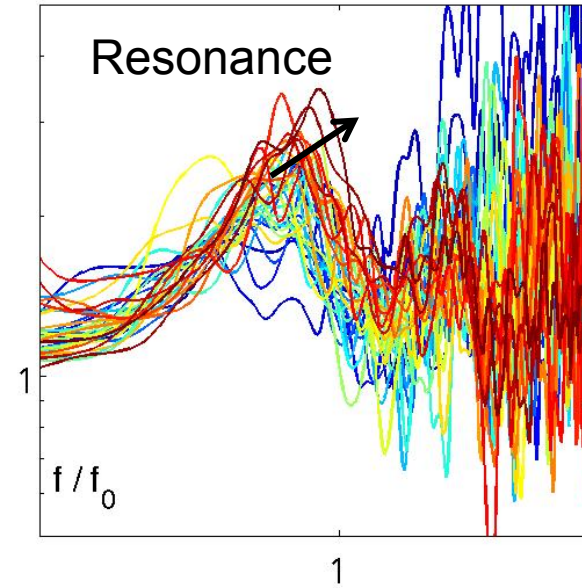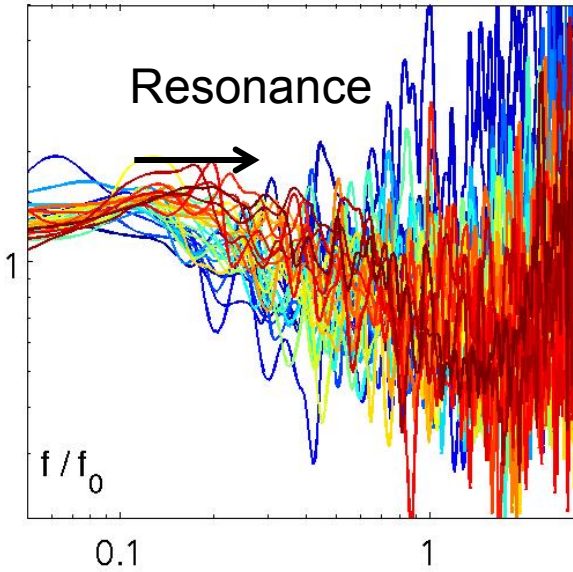
Amplification factors @ SC stations for GM predictions
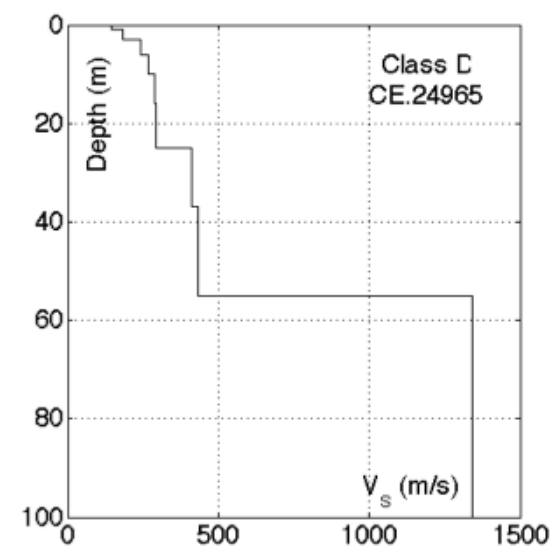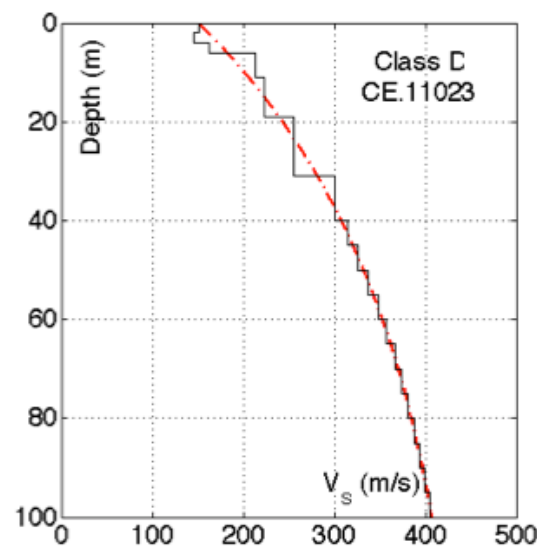
Nonlinear amplification factors *f* (Intensity)
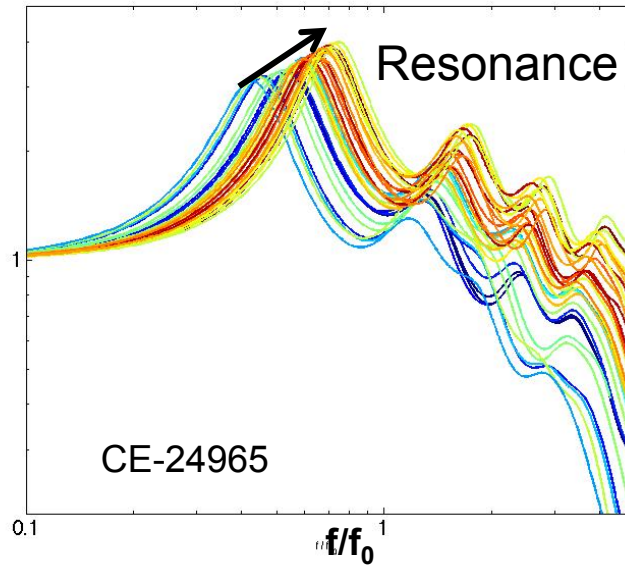
Nonlinear amplification factors 𝑓 (Frequency)
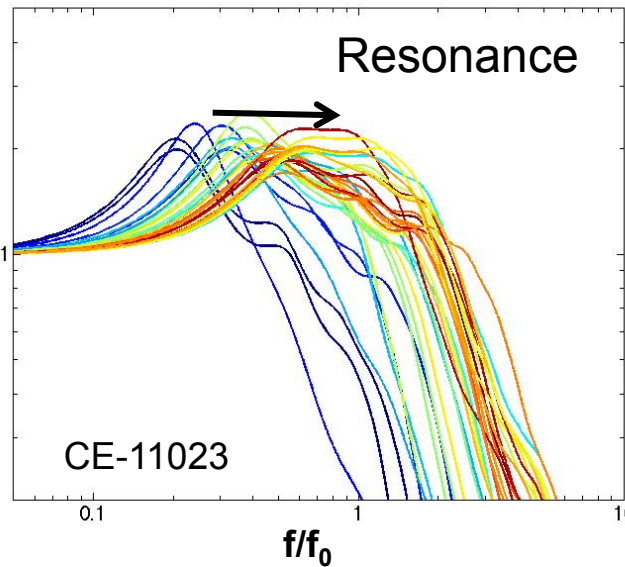
Scaled to 0.25g incident acceleration amplitude

GM Simulation Validation @ SC Strong Motion Stations
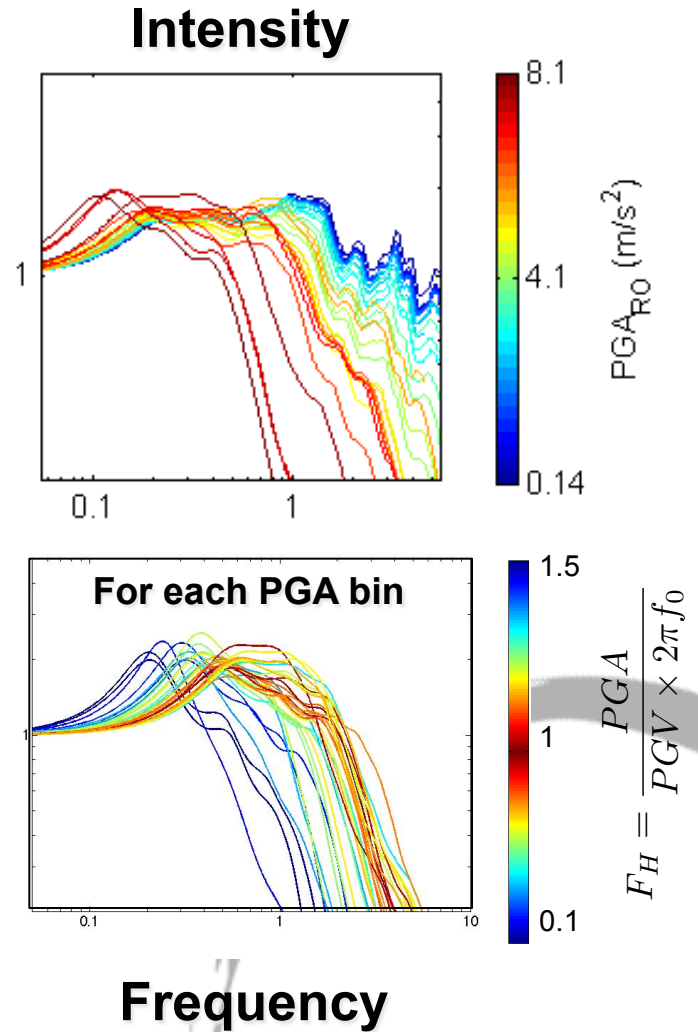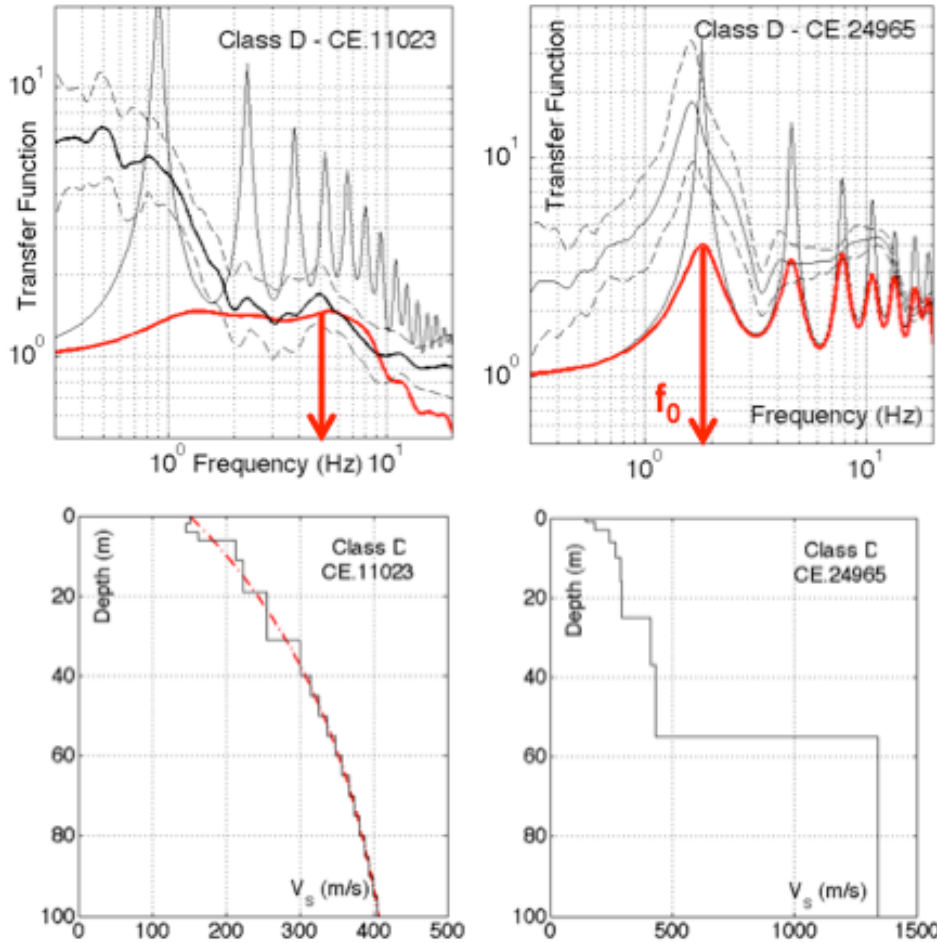
Nonlinear Site Response Validation @ KIK-Net Stations
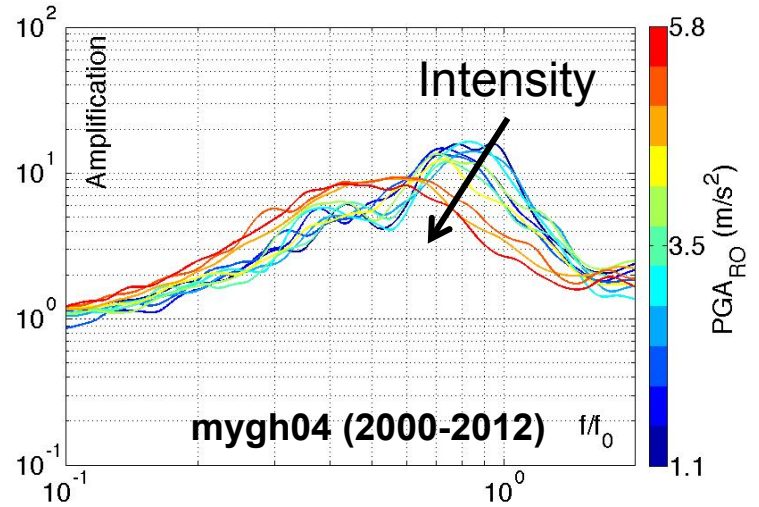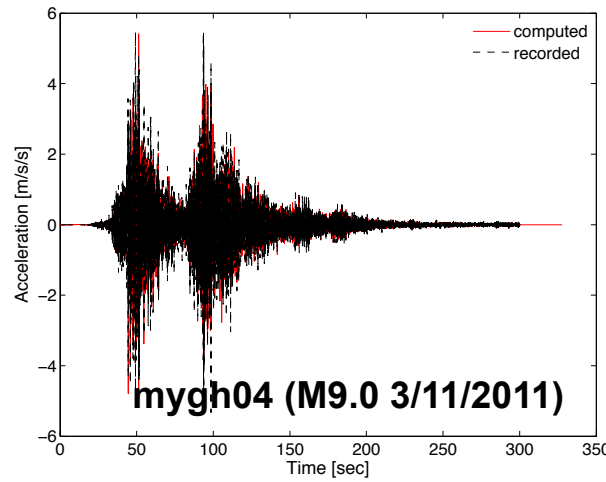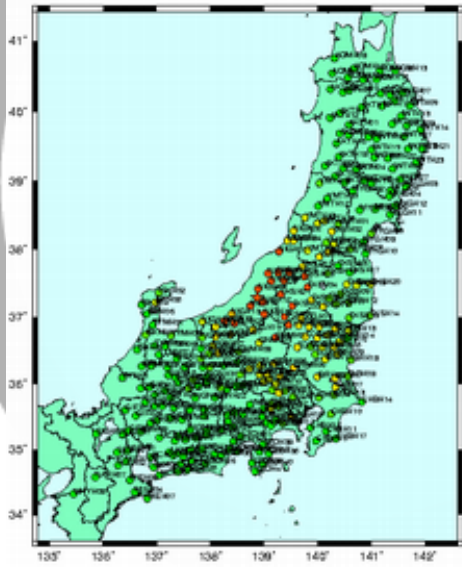
- Site-specific response analyses: Li & Assimaki (2010) nonlinear model

  - Parameters from downhole array inversion (linear and nonlinear)

  - PRENONLIN team site characterization @ KIK-net stations

  - NIED reported profiles; Literature e.g. Thompson et al (2010)

- Derivation of $\mathbf{AF_{NL}} = f\,(\,\mathbf{PGA_{RO}},\,\mathbf{F_H}\,)$ at selected stations

- Validate with statistically independent sample of station recordings

- Correlation of analytical $\mathbf{f_0^{site}}$ with empirical $\mathbf{H/V}$ (weak motion & noise)

Nonlinear Site Response Validation @ KIK-Net Stations

Thank you!