Nonlinear Site Effects: Numerical Modeling of Field and Laboratory Data Observations

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Presentation Outline

- Empirical evidence of nonlinear site effects
- Some models of nonlinear site response
- 1D modeling of the Kushiro-Oki station
- 2D modeling of the Grenoble basin
- Empirical constraints to nonlinear site response

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Kobe: Jan. 1995, M6.9

Vertical Settlement

Photo 5. Sand boils and seismometer at the Port Island Borehole Array Station installed by Kobe Development Bureau

The borehole array station installed in northwest of Port Island recorded ground motion at four depths (0 m, −16 m, −32 m, −83 m). Extensive sand boils were observed at the same site. (by F. Oka, Gifu University).

Photo 11. Damaged caisson type quay walls at Port Island in Kobe Port

Many caisson type quay walls were damaged in Kobe Port. Seaward displacements of the caisson walls were about 5 m at maximum and 3 m on an average. The soils behind the wall settled accordingly. (by S. Iai, Ministry of Transport)

Lateral Spreading

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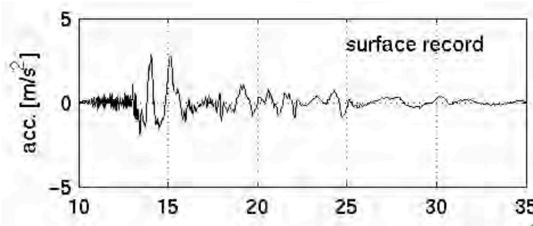
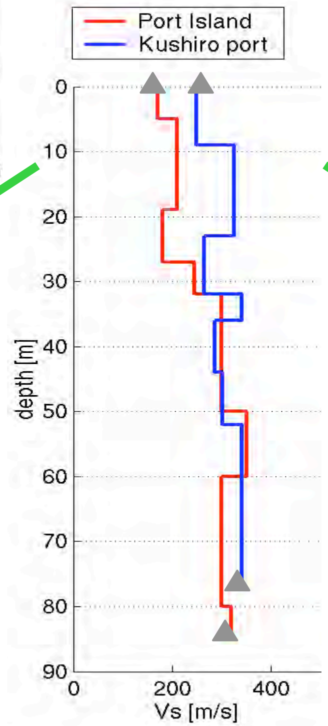
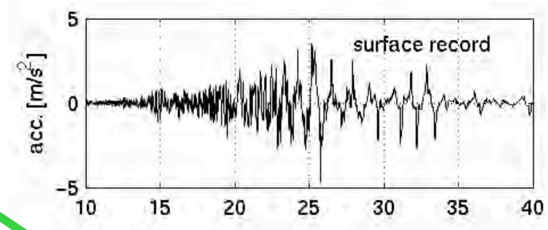
Port Island, Kobe / Kushiro Port







Loose sand => licuefaction

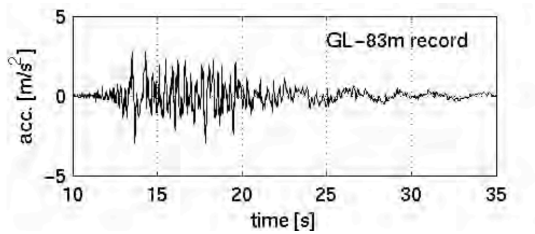
-Lowpass filtering

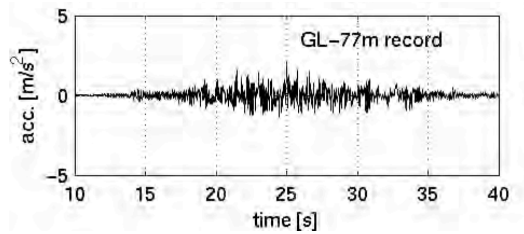
-Deamplification

Dense sand => cyclic mobility

- High frequency peaks

- Amplification





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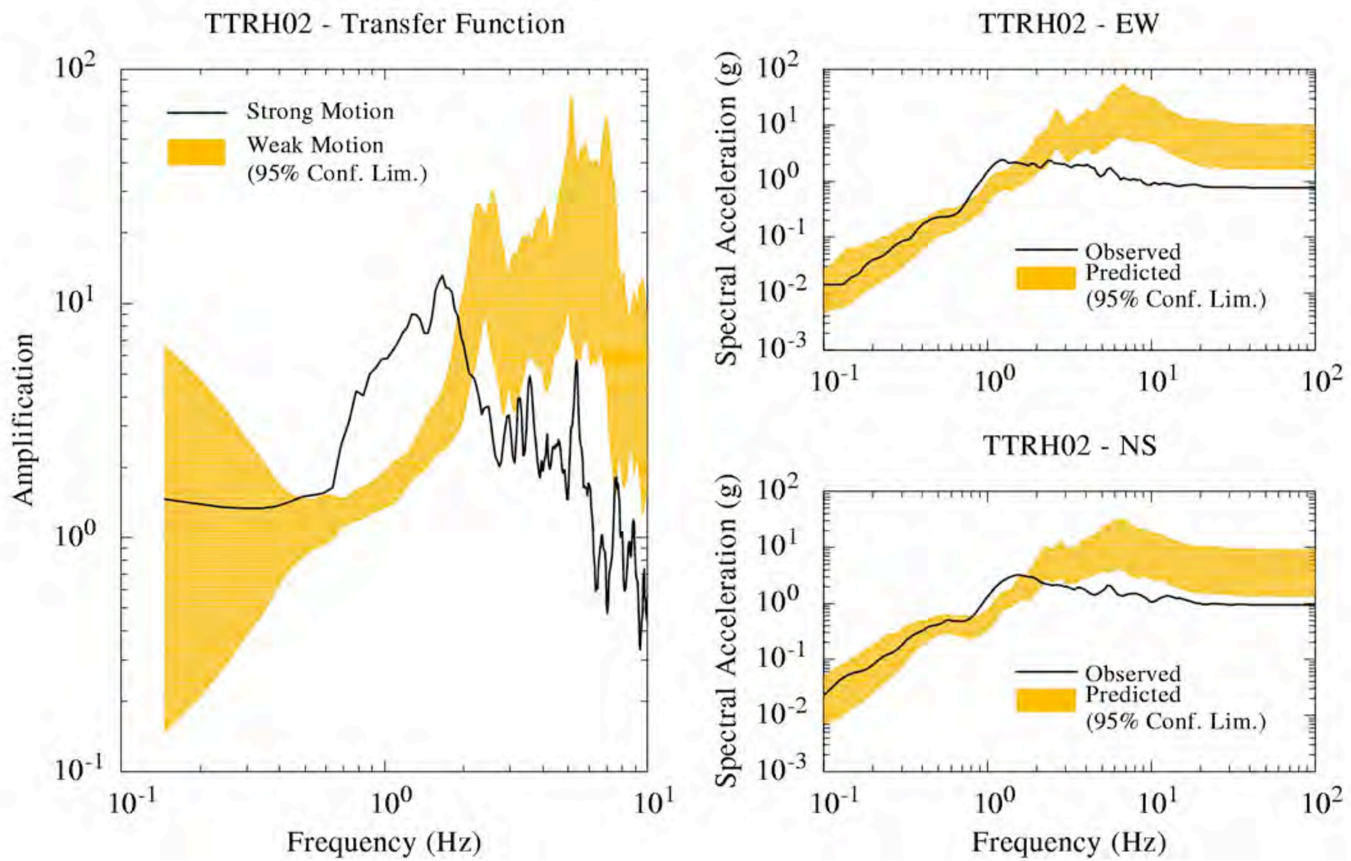
Nonlinear Effects: TTRH02 Station (Japan)



Site amplification is different for strong ground motion

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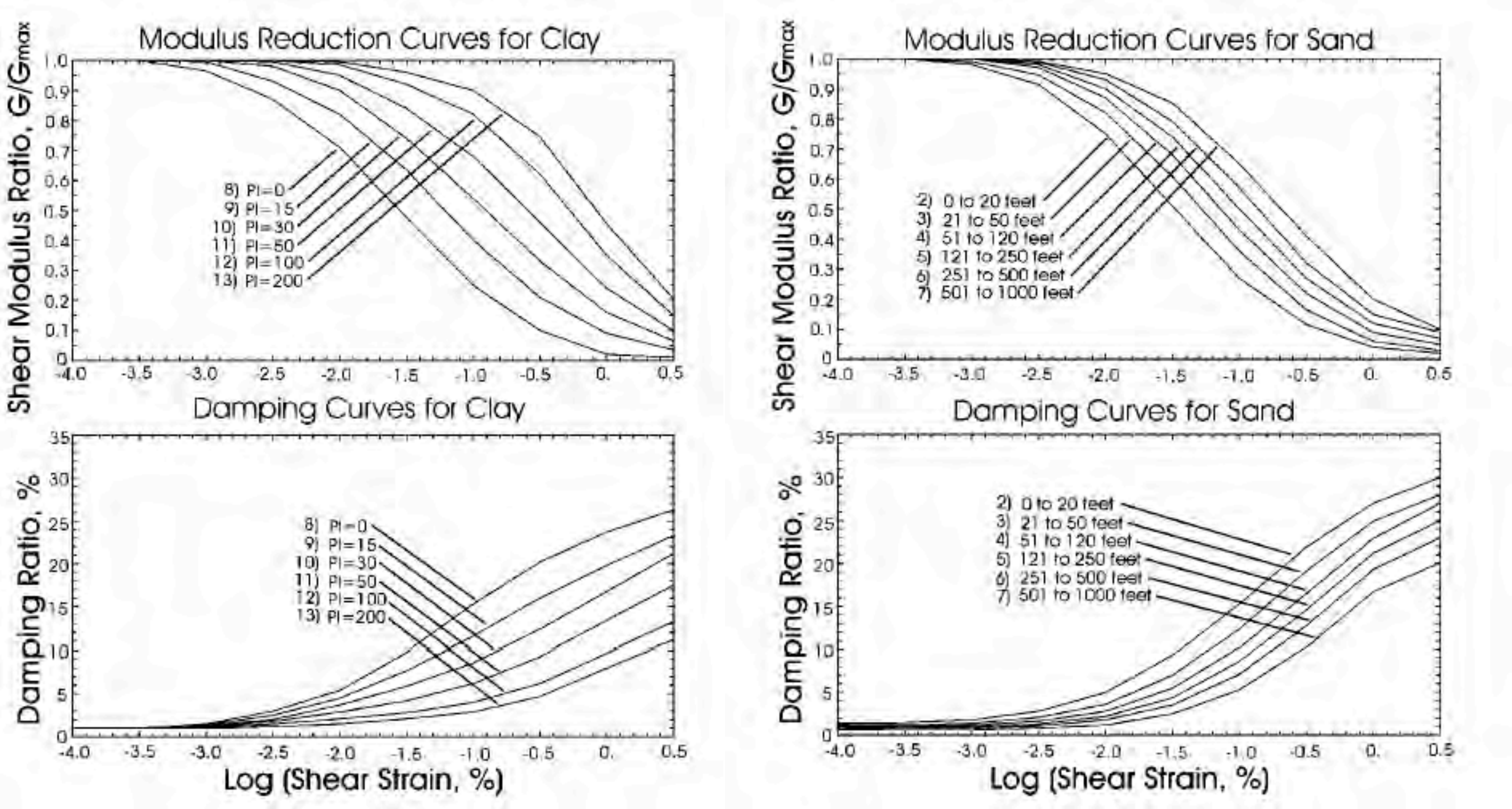
Some models of nonlinear site response

EPRI modulus reduction and damping curves



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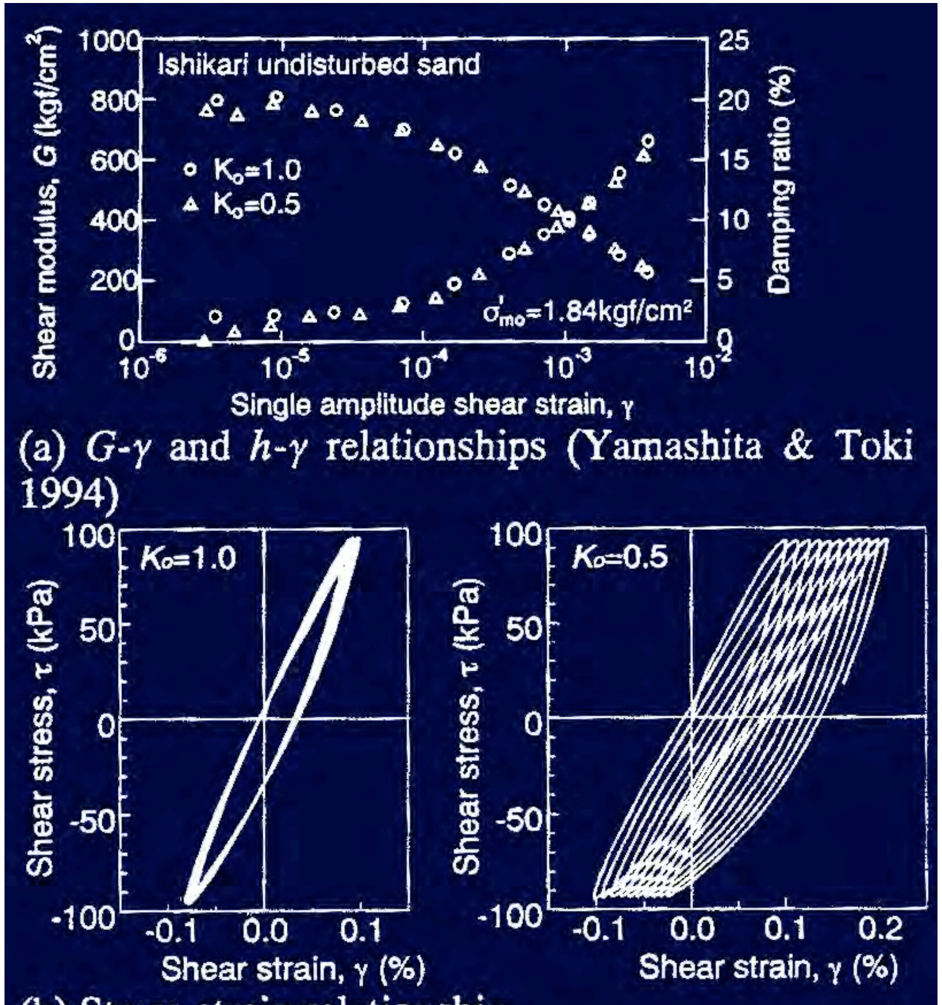


(a) G-γ and h-γ relationships (Yamashita & Toki 1994)

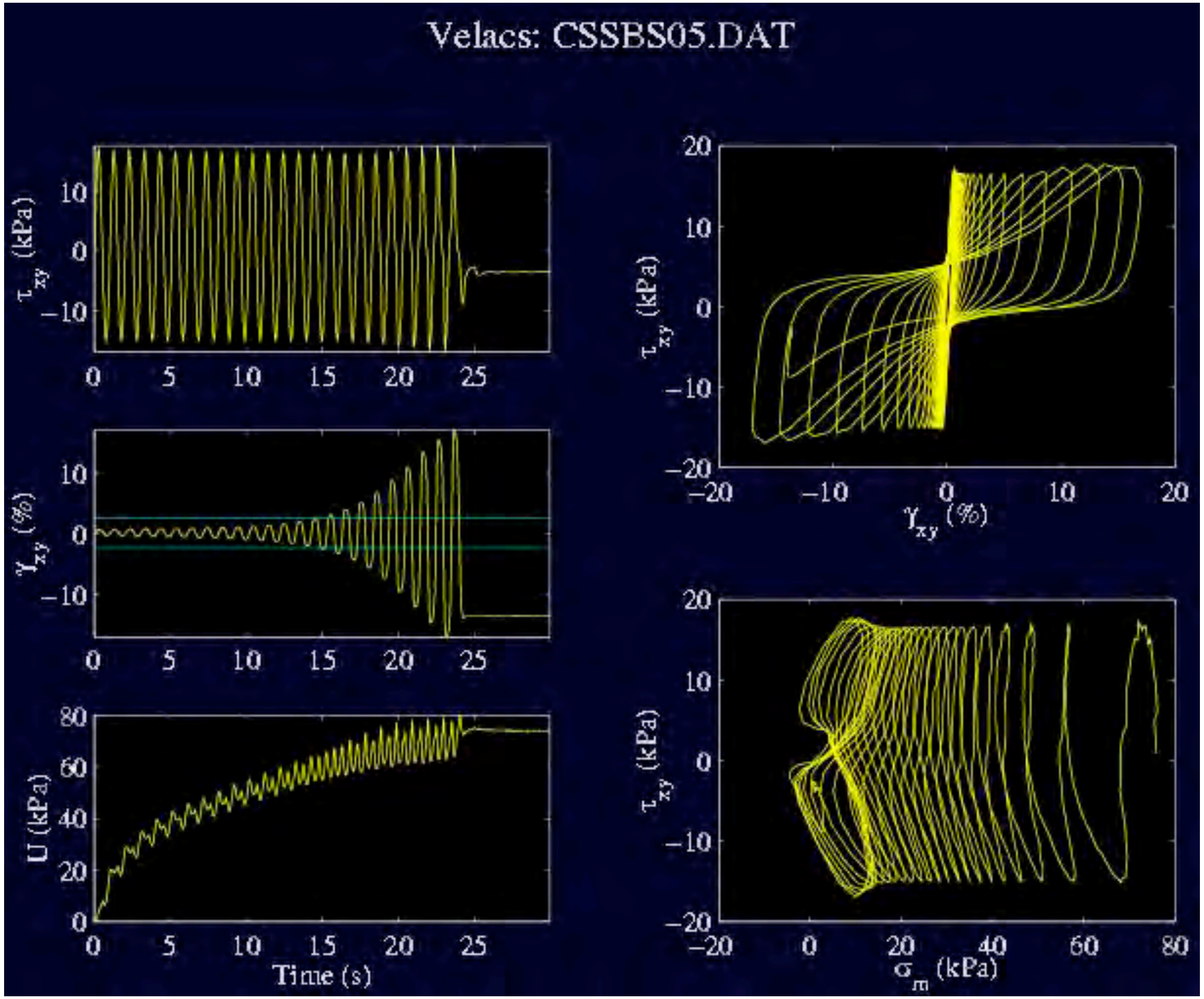
(b) Stress-strain relationship

Figure 6. Dynamic deformation characteristics under isotropic and anisotropic initial stresses.

Classical Laboratory Data Are Limited

After Ishihara (1996)

Velacs Project, 1992 (pore pressure effects)



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How is the transfer function affected?

1. The shear modulus is computed as $G=\rho\beta^2$
2. The fundamental frequency of the soil is $f_0=\beta/(4H)$
3. If G changes, so does β :
   if $G(-) \text{--->} \beta(-) \text{--->} f_0(-)$

- Deamplification: the damping increases (pay attention)
- Increase of the signal duration (long period waves arrive later)

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Numerical solution

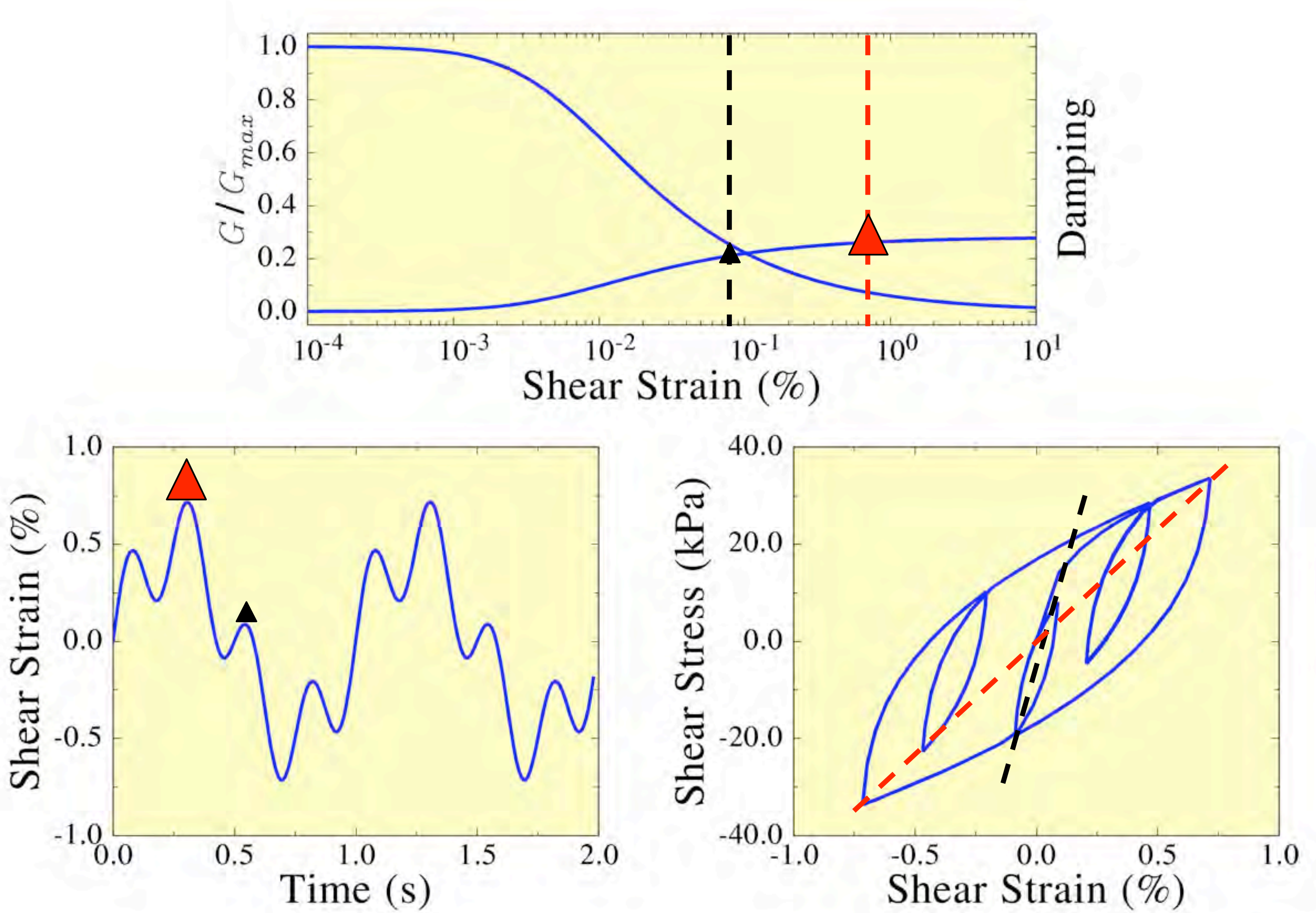
Why?

- There is no analytical solution
- Finite differences, spectral elements, finite elements methods

Boundary conditions:

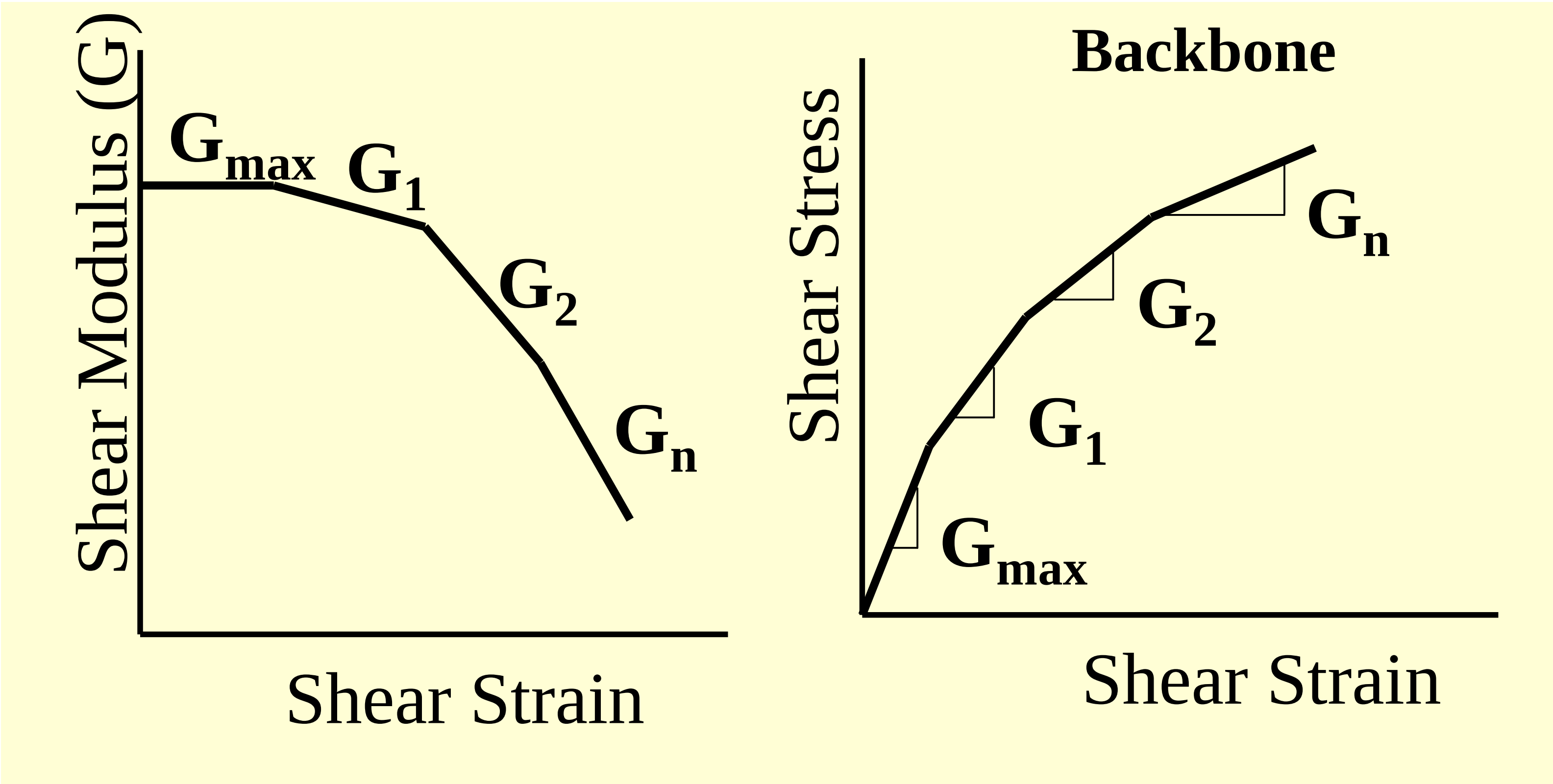
- Surface: free surface effect
- Bedrock: elastic boundary conditions (transmitted waves) or rigid boundary conditions (complete reflection)

The equivalent linear model (1972)



G-γ frequency dependent (Assimaki and Kausel, 2002)

Iwan-Mroz Model (1967)



Reconstruction of backbone from the modulus reduction curve

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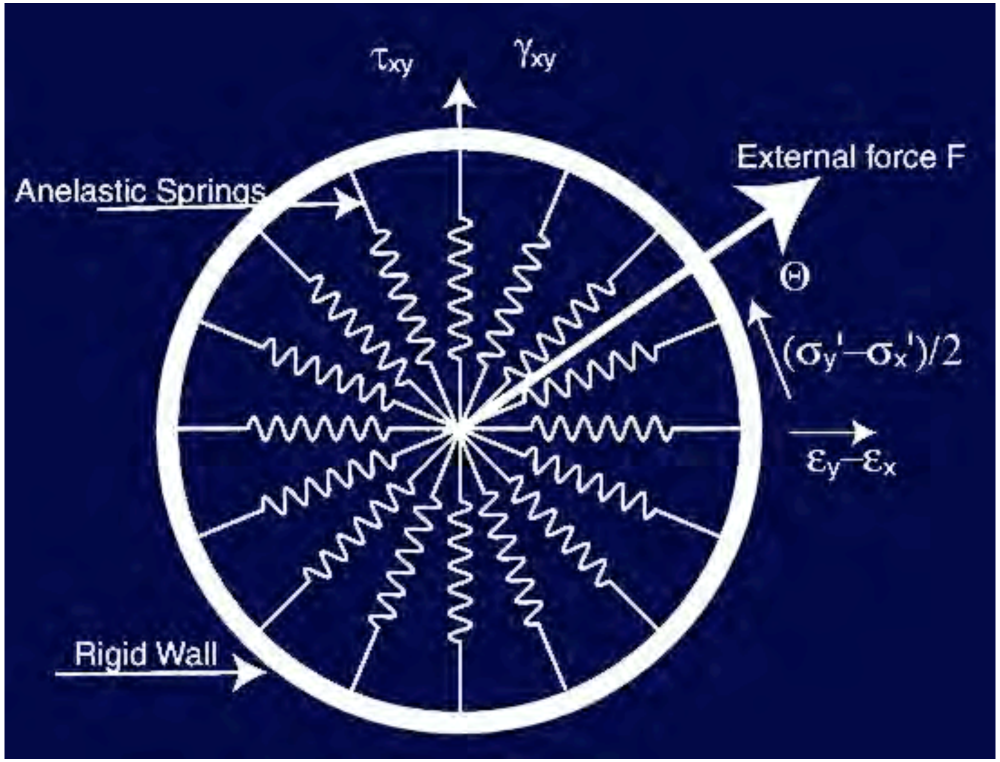
Multi-spring Model (1)



- 2D plane strain model
- Each spring obeys the hyperbolic model
- Hysteresis follows the generalized Masing rules
- Capability to model anisotropic consolidation conditions

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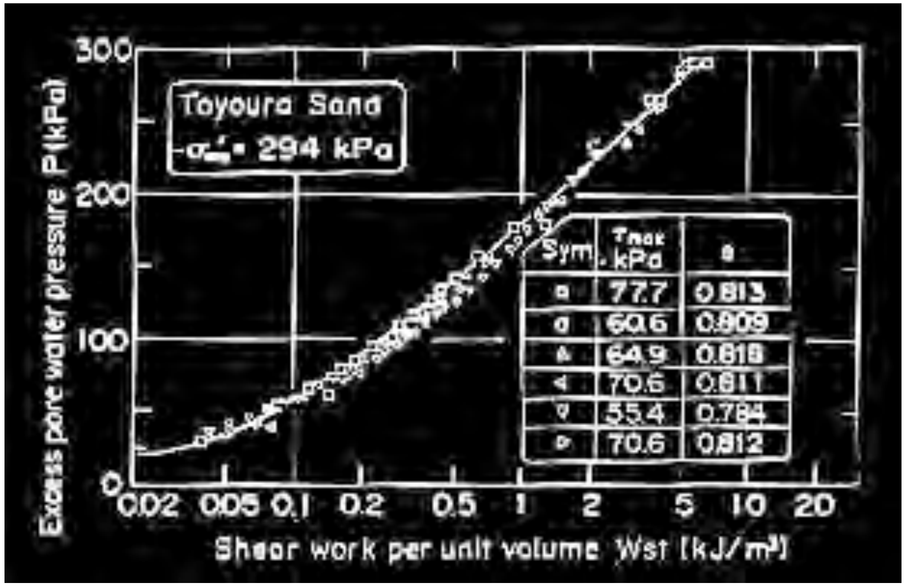
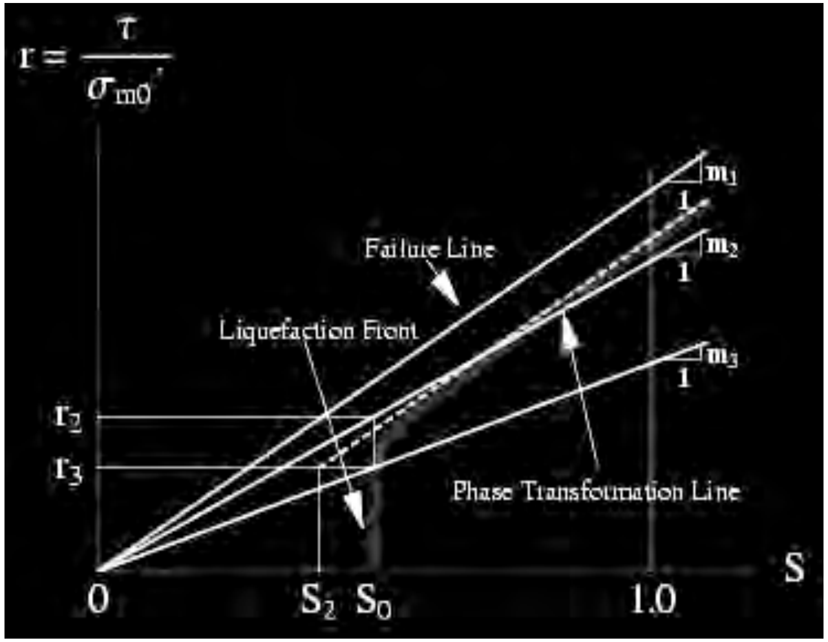
Multi-spring Model (2)

- Pore pressure excess is correlated to shear work
- Model space has five parameters to take into account dilatancy
- Plastic parameters are angle of internal friction, and angle of phase transition
- Elastic parameters are thickness, Q, density, P and S wave speeds





1D modeling of the Kushiro-Oki station

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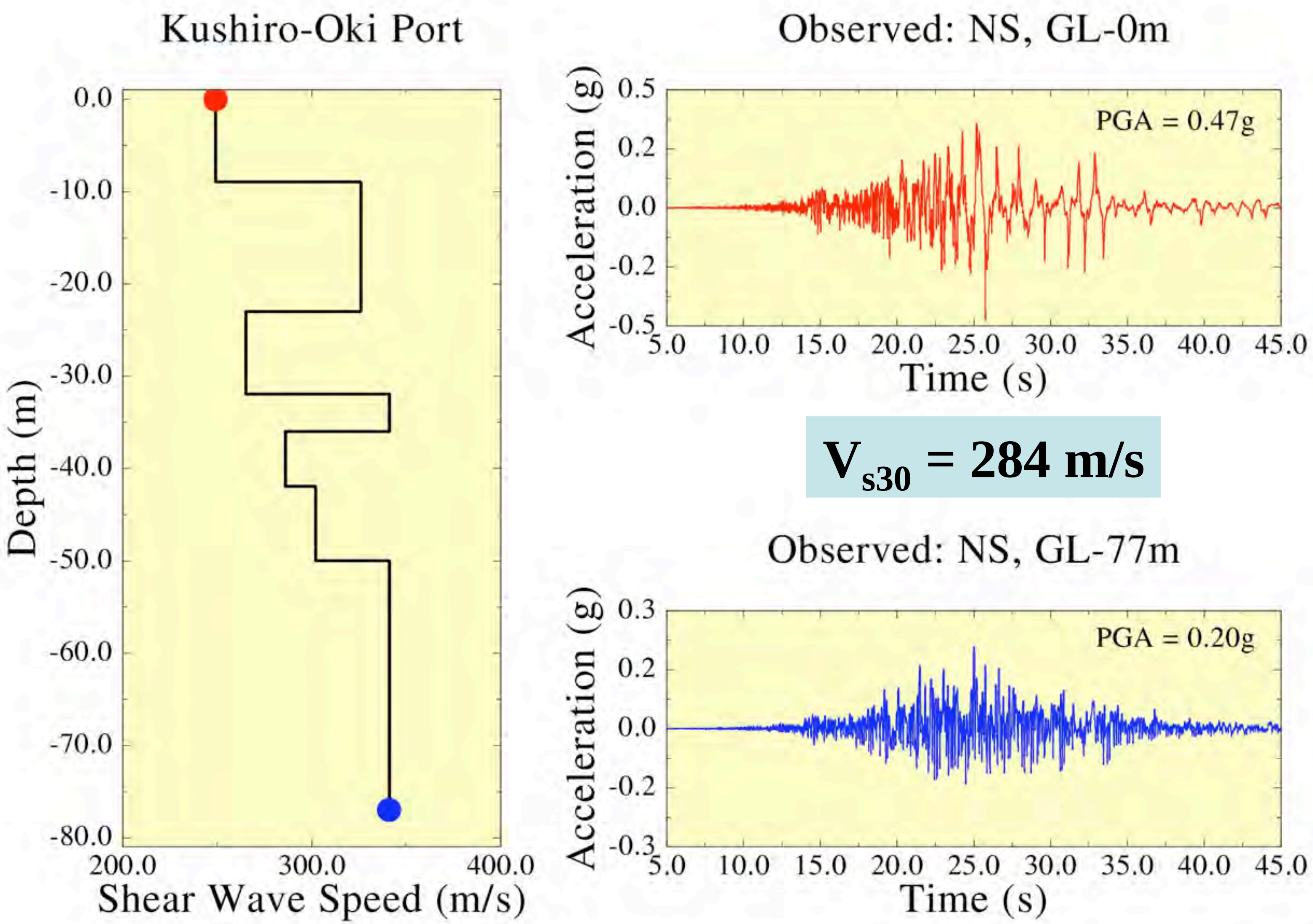
The M7.8 Kushiro-Oki 1993 event



V_{s30} = 284 m/s

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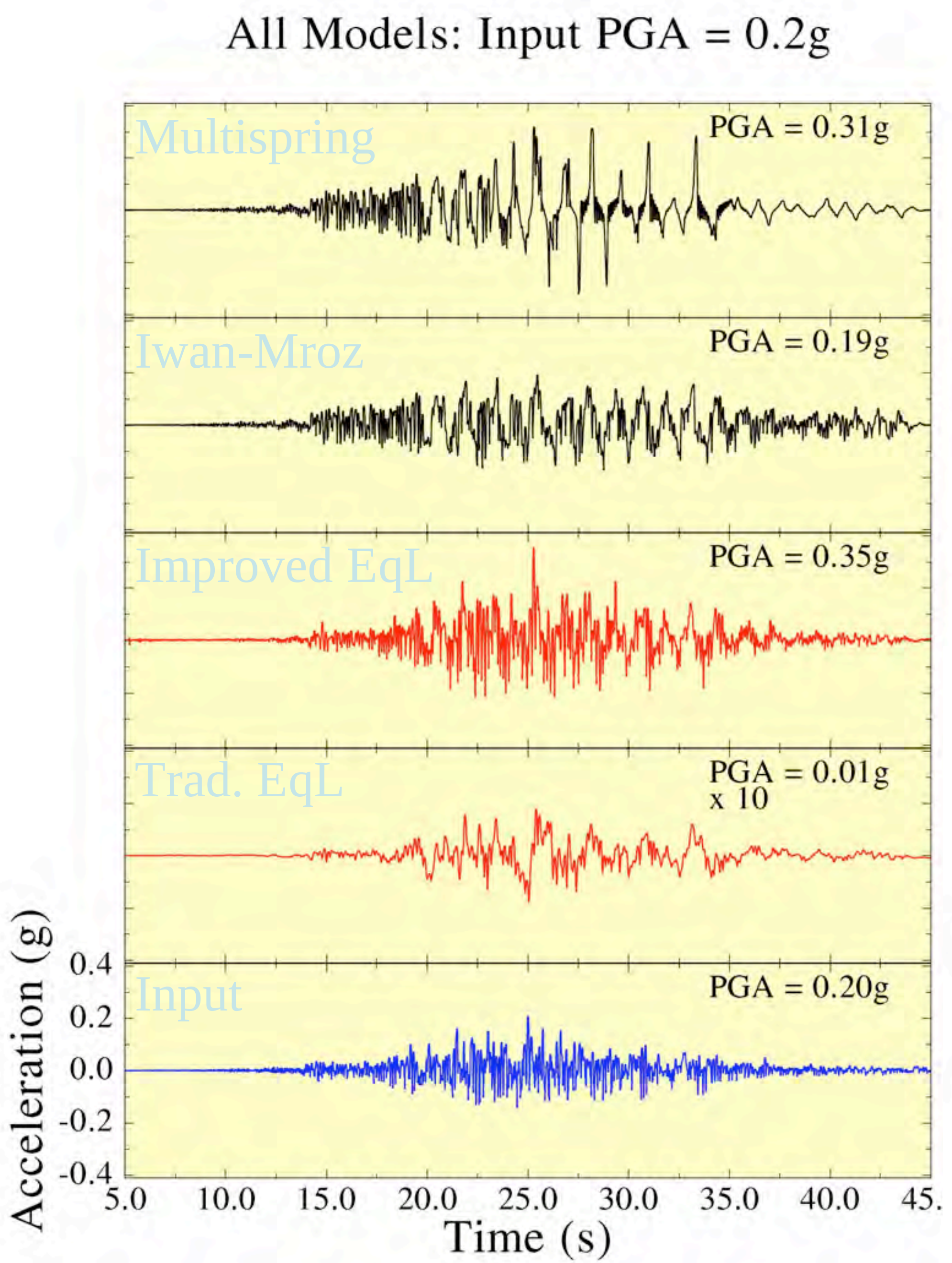
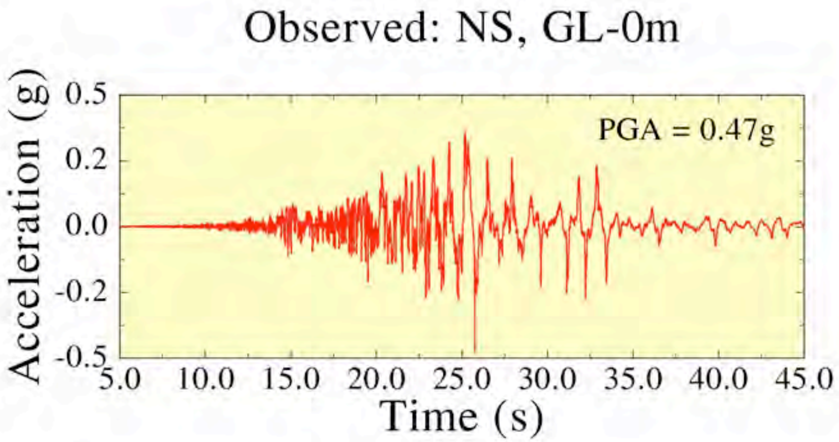
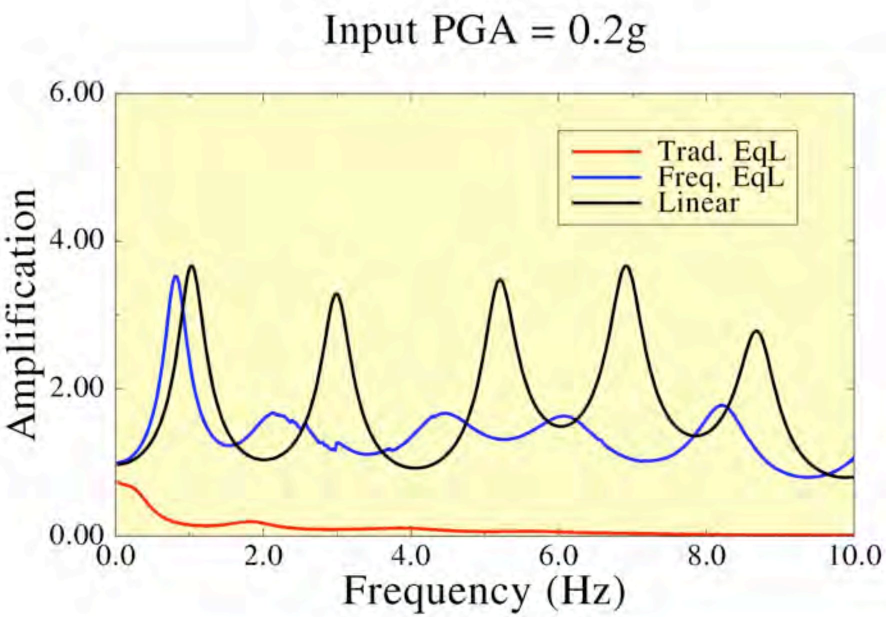
Dense sand deposit, first studied by Iai *et al* (1995)

Results





Pore pressure analysis may be needed if soil is saturated



Partial Conclusions

- ✓ The choice of rheology is rather important in the modeling of nonlinear site response.
- ✓ Equivalent linear model should be avoided for soft soils (Vs30 < 300 m/s). However, it is OK for stiff materials at low PGA's (PGA < 0.2g).
- ✓ The Iwan-Mroz represents better the nonlinear soil behavior with the same data as the Eq. Linear method.
- ✓ A better soil characterization is needed when having saturated medium.

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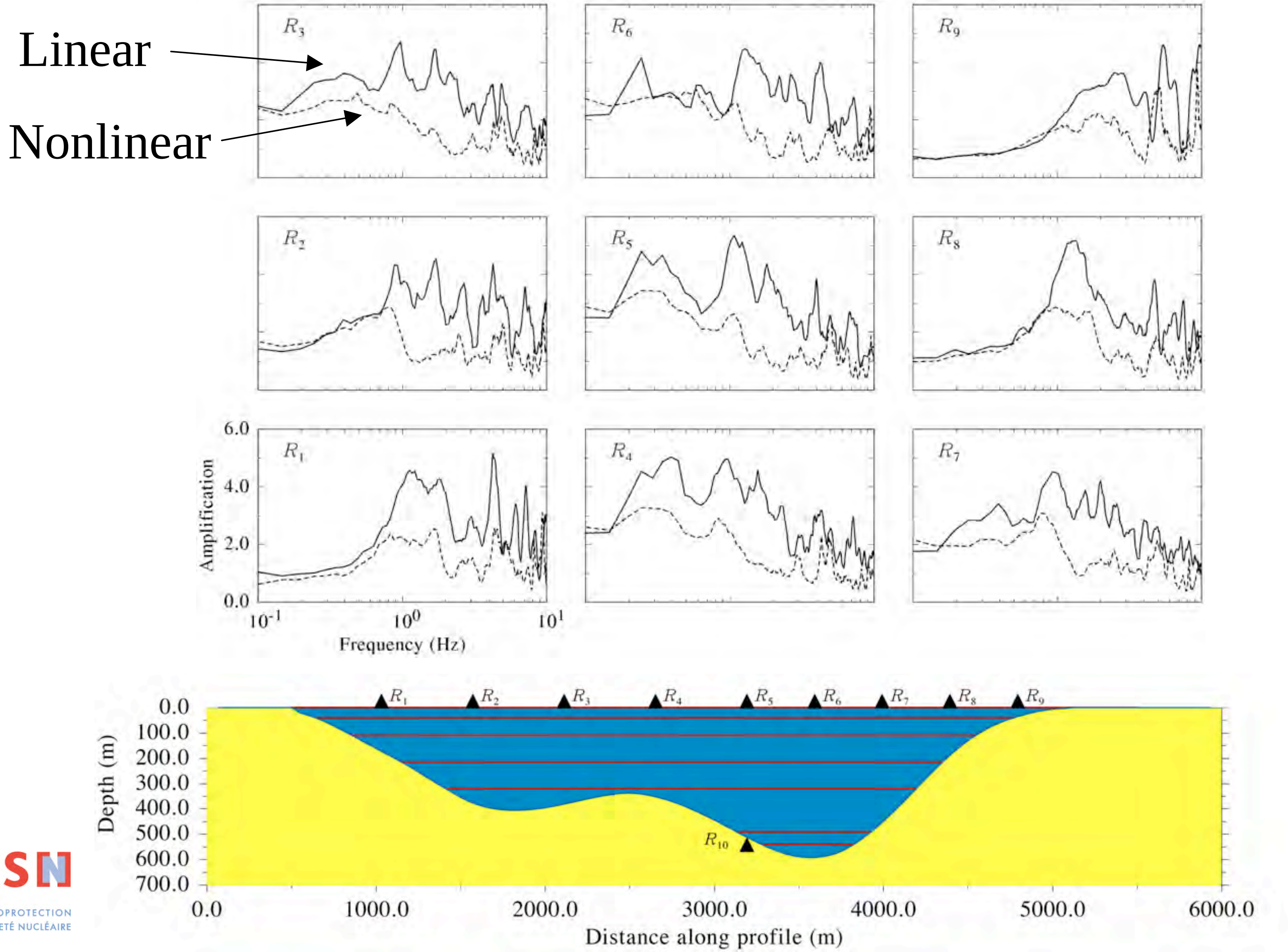
2D linear and nonlinear response of the Grenoble basin



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What the field data say about nonlinear effects

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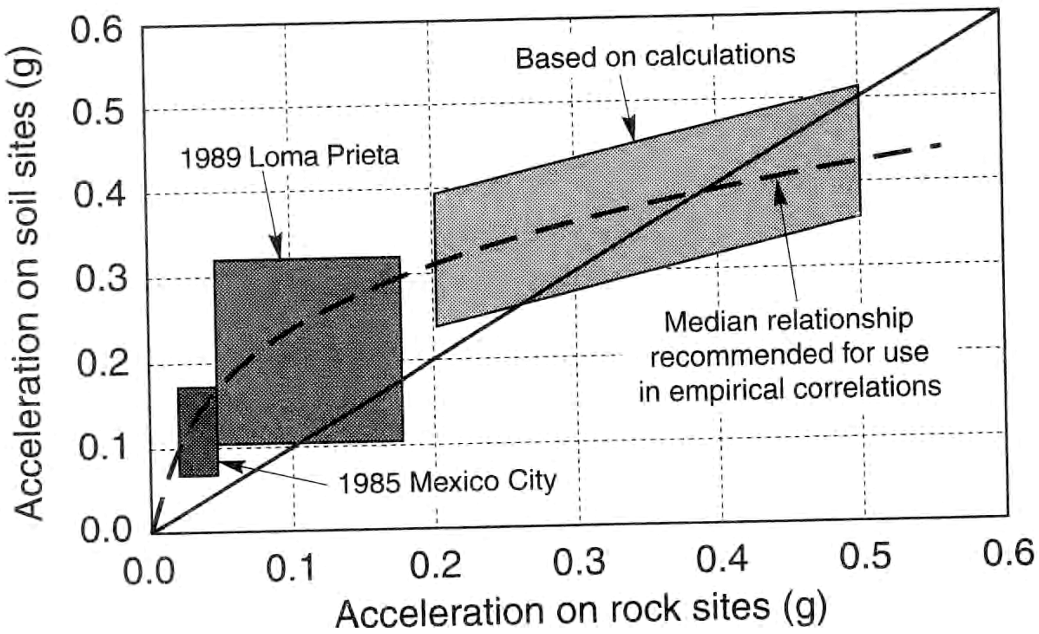
Observations (1)



- Deamplification expected above 0.4g (rock sites)
- Results biased by simulations only

(Idriss, 1990)

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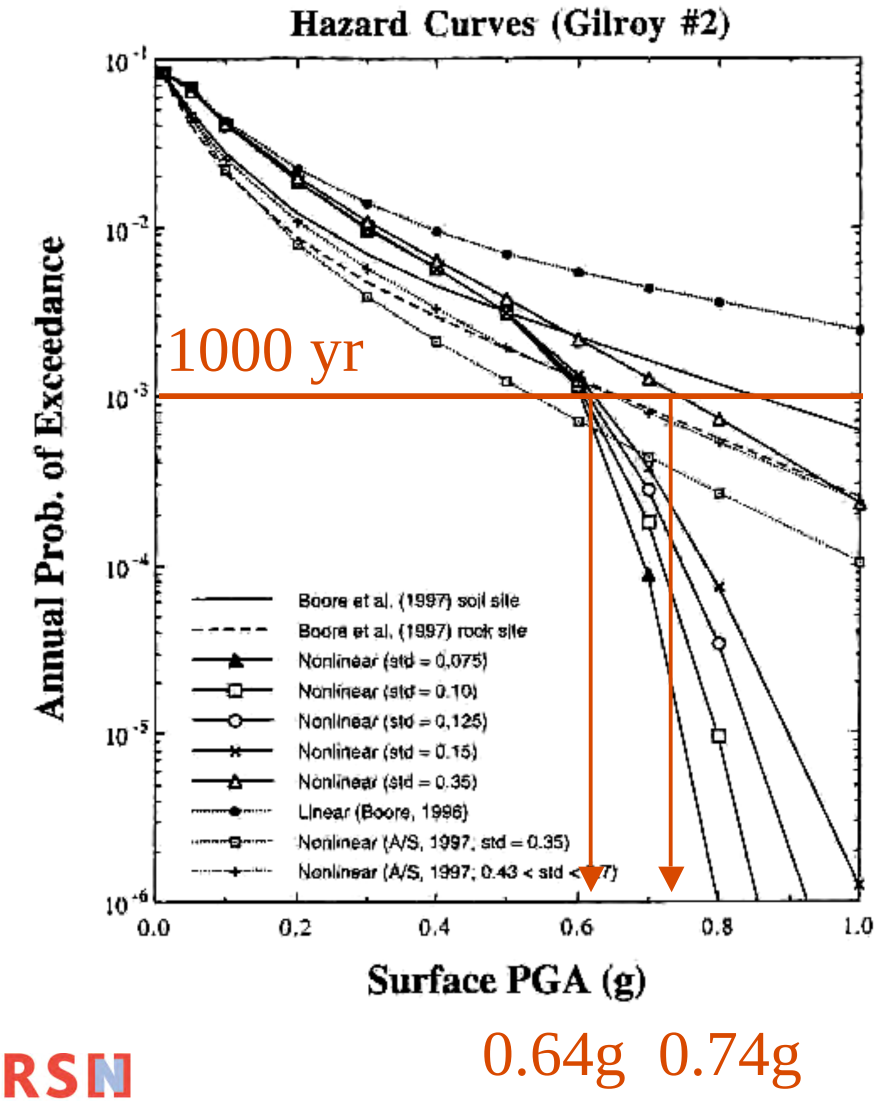
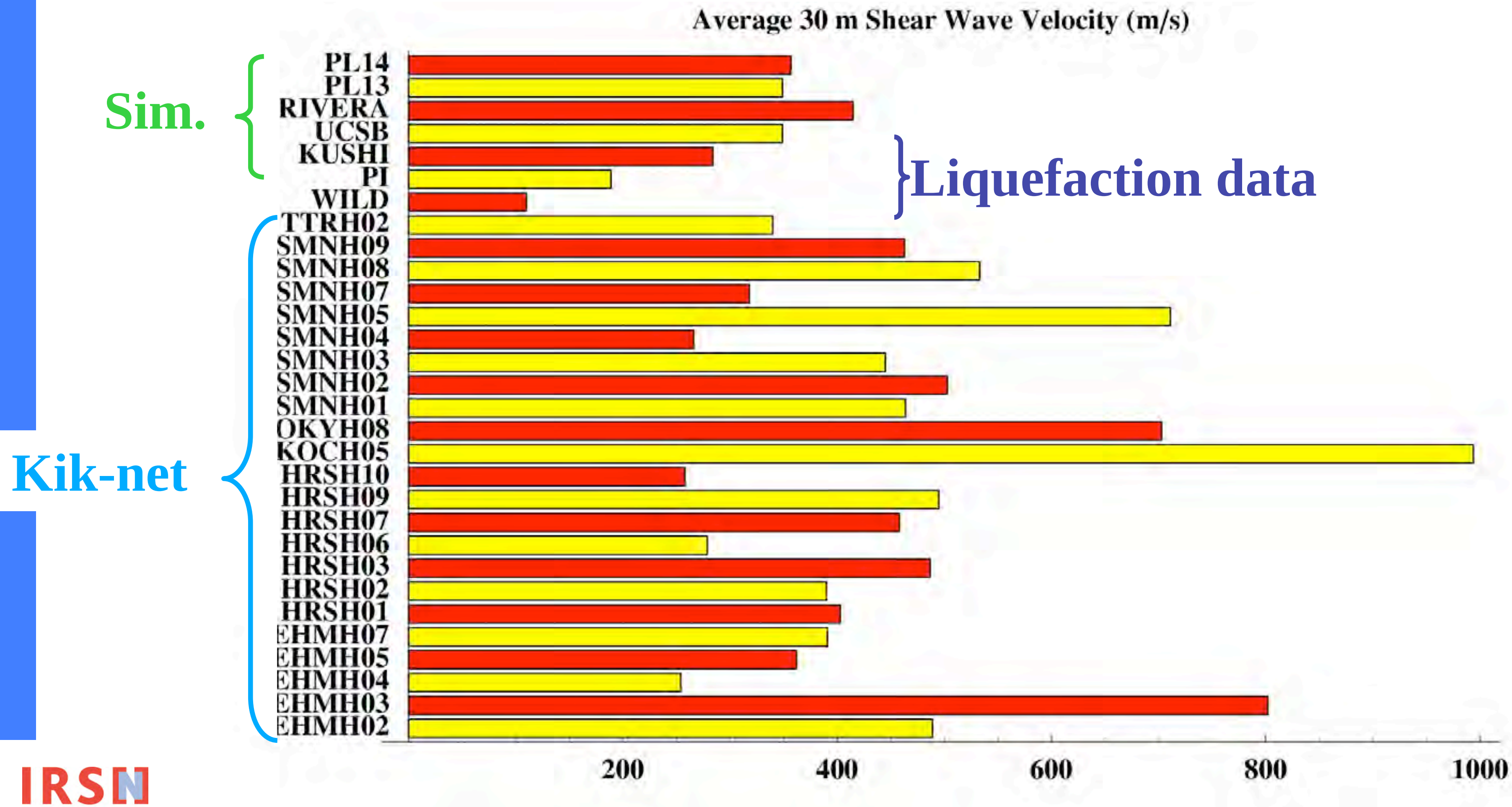
Observations (2)



- PSHA taking into account nonlinear site response
- The return periods are higher than the ones obtained with linear site response

(Tsai, 2000)

Vs30 distribution



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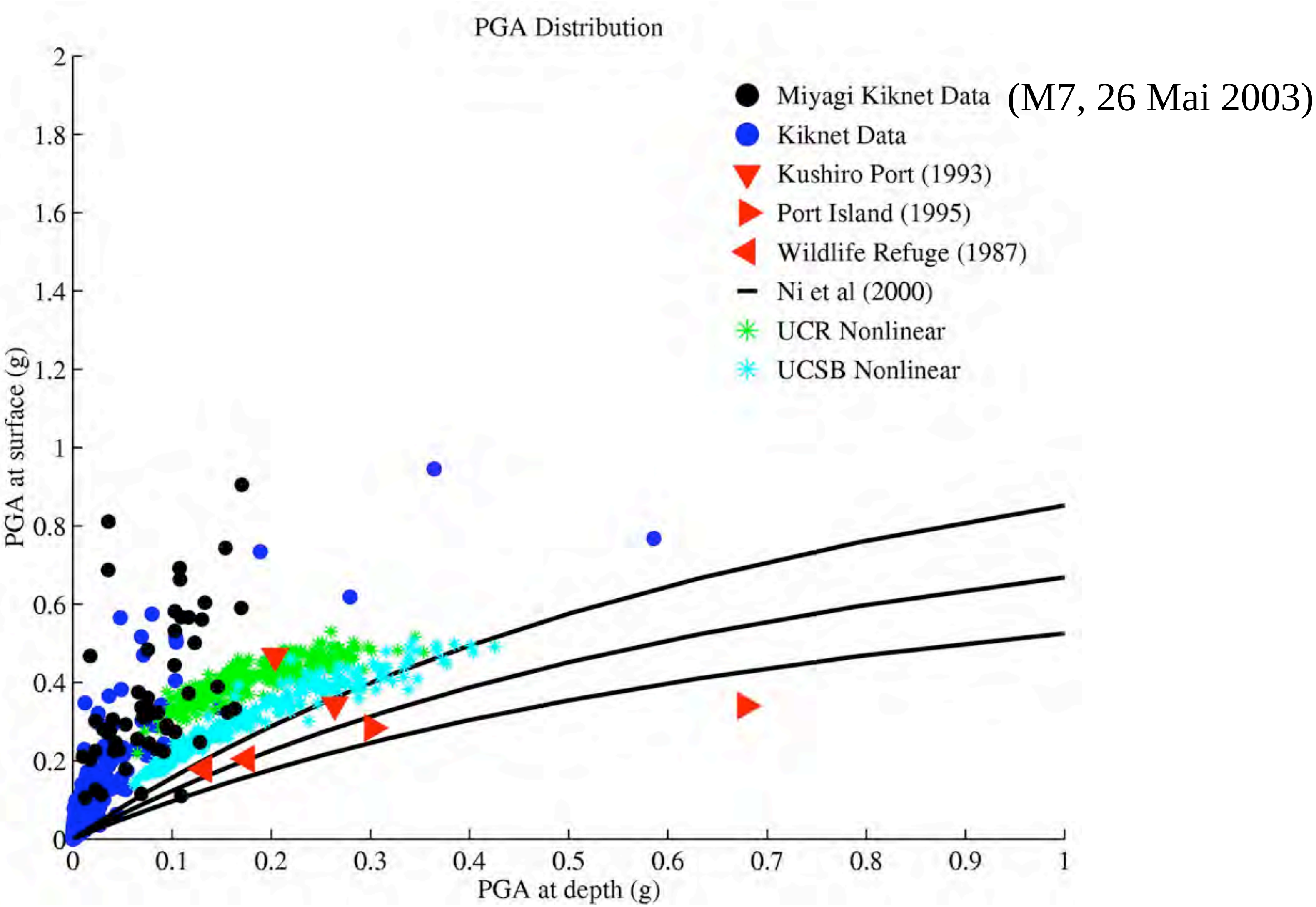
PGA distribution (Kik-net)



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Partial Conclusions

- Nonlinearity apparently begins for a PGA > 0.1g for these type of soils (300-400 m/s).
- These soils are less nonlinear than we might think. This is important for areas with moderate seismicity (high amplification is expected due to low nonlinear effects).
- Pore pressure produces lot of scattering on the PGA and response spectra data.

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Laboratory/Field Needs

- ✓ Stress-strain time histories from simple shear and/or triaxial dynamic tests (pore pressure included).
- ✓ Static triaxial tests to obtain the angle of internal friction and cohesion (material resistance).
- ✓ Liquefaction resistance curves (keeping the stress-strain time histories for a complete modeling)
- ✓ Accurate estimation of P and S wave velocity profiles.
- ✓ Estimation of the coefficient of earth at rest (odometer lab test - OCR)

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