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WHAT STARTS HERE CHANGES THE WORLD

Site Response Implications Associated with Common Methods used to Account for Vs Profile Uncertainty

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QuakeCoRE Meeting

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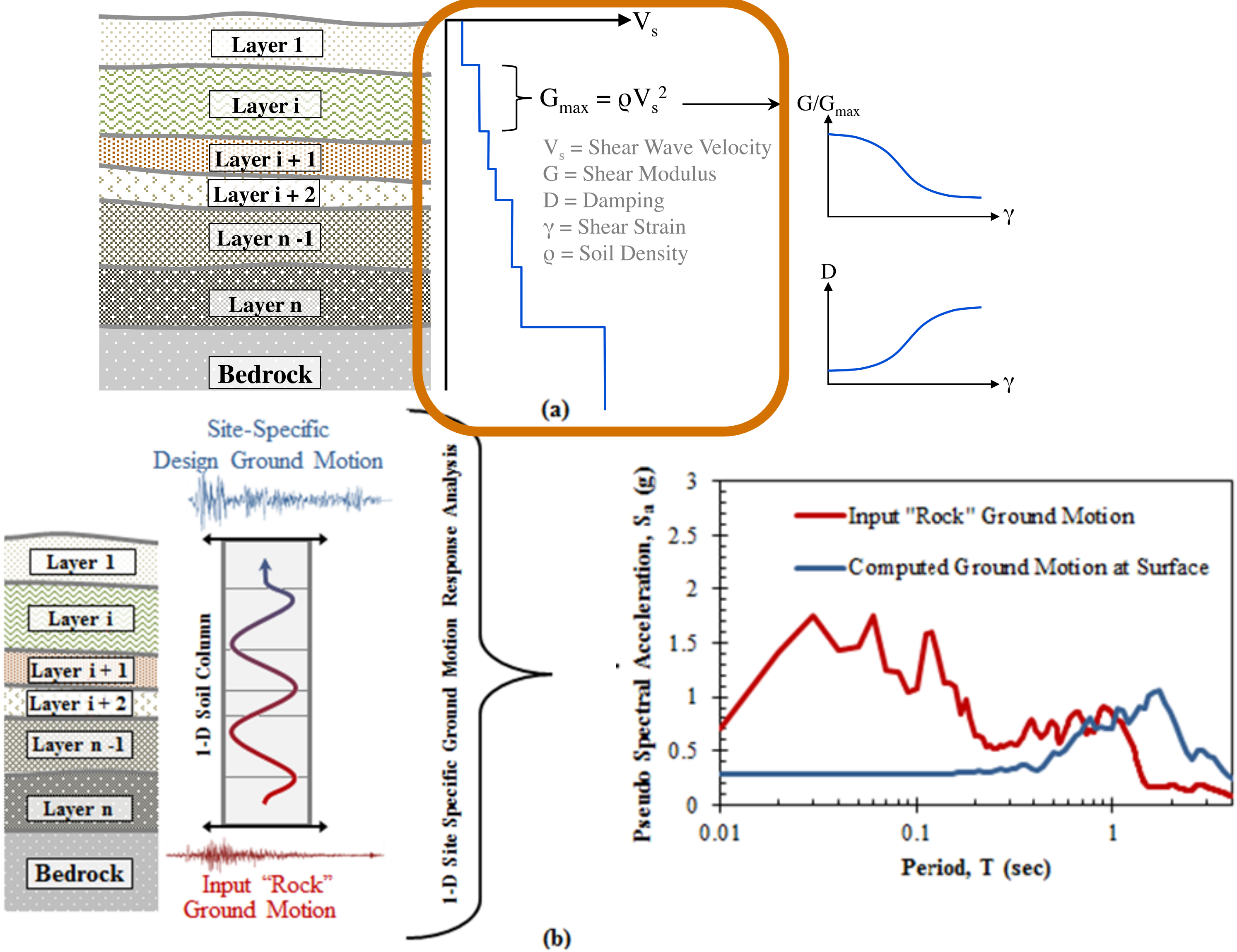
Longhorns

1D Site Response Overview



How do YOU Account for Vs Uncertainty in Site Response?

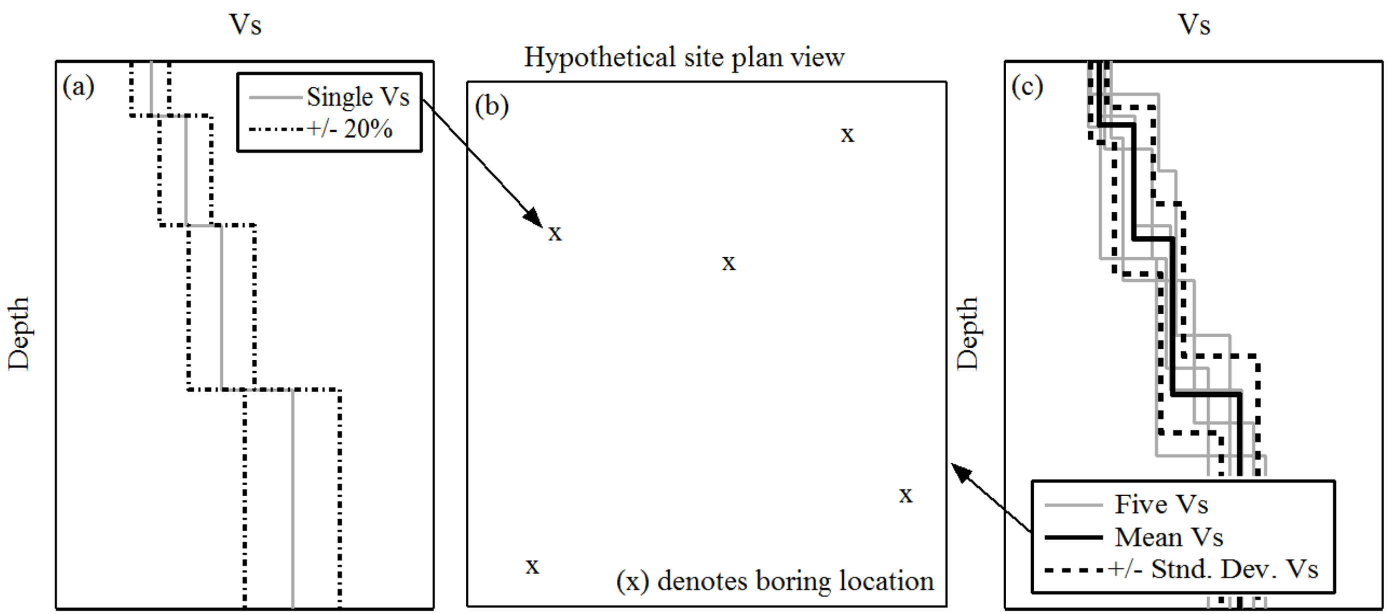
- Codes/Guidelines for Site Response
  - ASCE 7-10 "The uncertainties in soil properties shall be estimated."
  - AASHTO (2011) "Uncertainties in the soil modulus… should be considered in the modeling effort."
- DOT survey by Matasovic and Hashash (2012)
  - 33% used a median Vs profile with upper- and lower-bound
  - 23% did not directly account for Vs uncertainty
  - 13% used Vs randomization models such at Toro (1995)

Epistemic Uncertainty vs. Aleatory Variability

- Epistemic uncertainty: data uncertainty, or a lack of scientific knowledge
- Aleatory variability: inherent randomness; related to spatial and vertical variability across a site
- EPRI (2012) Seismic Evaluation Guidance SPID
  - Epistemic uncertainty accounted for using median, upper- and lower-bound Vs profiles (i.e., "base-case" Vs profiles)
    - Median Vs +/- σ_{ln} with $\sigma_{ln} = 0.35$
  - Aleatory variability accounted for using correlated random perturbations to the base-case Vs profiles
    - Toro (1995) Vs randomization model

Vs Profiles from Borehole Methods

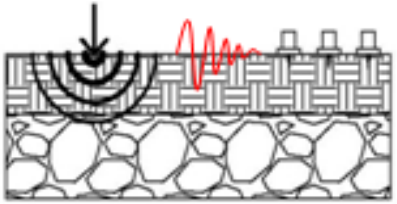
- In many cases, one Vs profile per site due to cost
  - Arbitrary upper- and lower-range base cases are often assumed (e.g., ± 20%)
- If multiple boreholes are drilled, spatial variability in thickness and Vs can be estimated using:
  - "Simple" statistical profiles (e.g., 16th and 84th percentiles)
  - Randomly generated profiles (e.g., Toro model informed by statistics)



Background: Vs Profiles from Surface Wave Testing

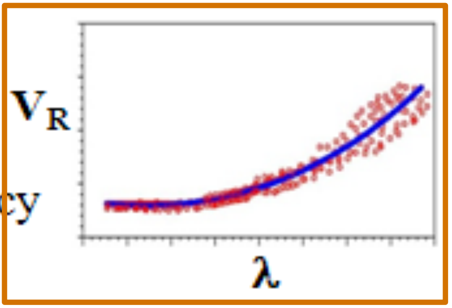
Acquisition

Field Data Collection:
Measurement of stress waves at the ground surface



Processing

Dispersion Curve:
Rayleigh Wave Phase Velocity vs. Wavelength/Frequency

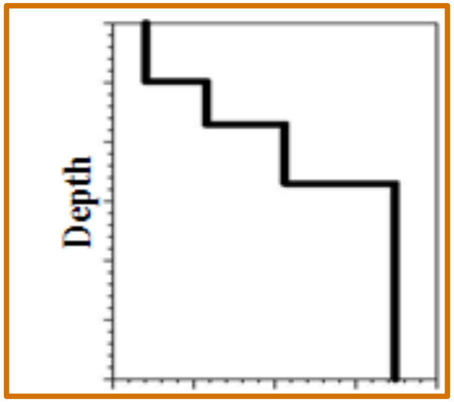


Robustly Determined by Experts: "site signature"

Inversion

Shear Wave Velocity Profile:
Variation of Small Strain Shear Modulus vs. Depth

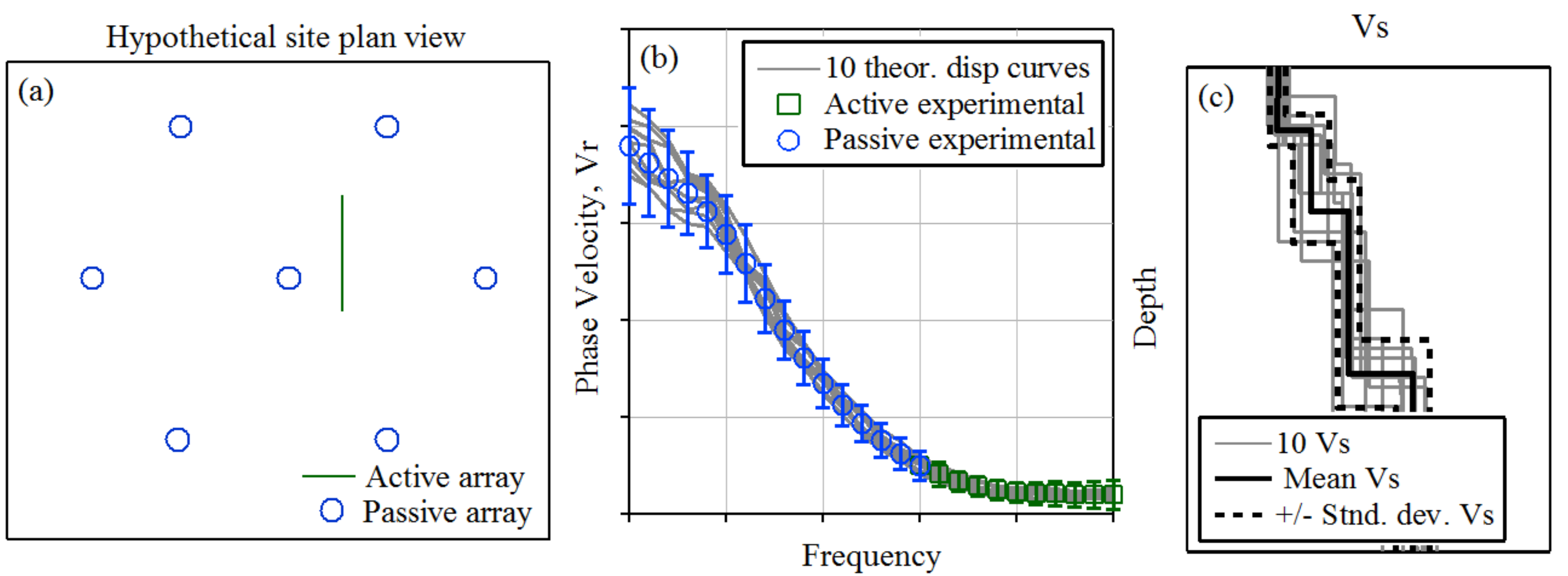
$$G_{max} = \rho V_S^2$$



Still Challenging for Experts: non-unique

Vs Profiles from Surface Wave Testing

- Surface wave arrays span large spatial extent (10's to 100's of m)
- Dispersion data uncertainty is both epistemic and aleatory
- Inversion to obtain Vs is ill-posed and non-unique
  - Many Vs profiles fit the data "equally" well (Foti et al. 2009)
  - Suites of Vs profiles should be provided, NOT a single Vs

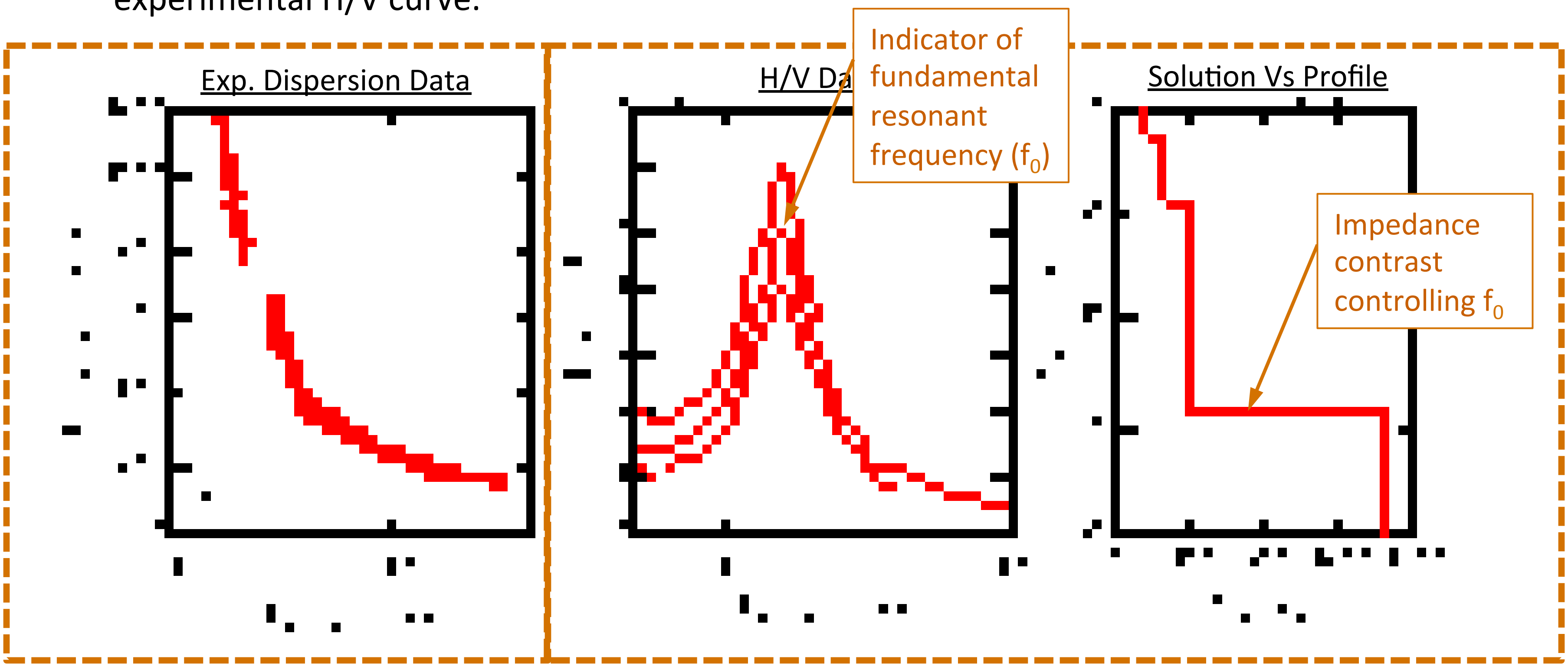


Objective

- Perform site response analyses using significantly different, non-unique Vs profiles derived directly from surface wave (SW) inversion (i.e., direct profiles).
- Compare accuracy and variability of site response estimates to those obtained using base-case and statistically-based, randomly generated profiles
- In order to assess accuracy, need a site for which a "true"/solution profile is available

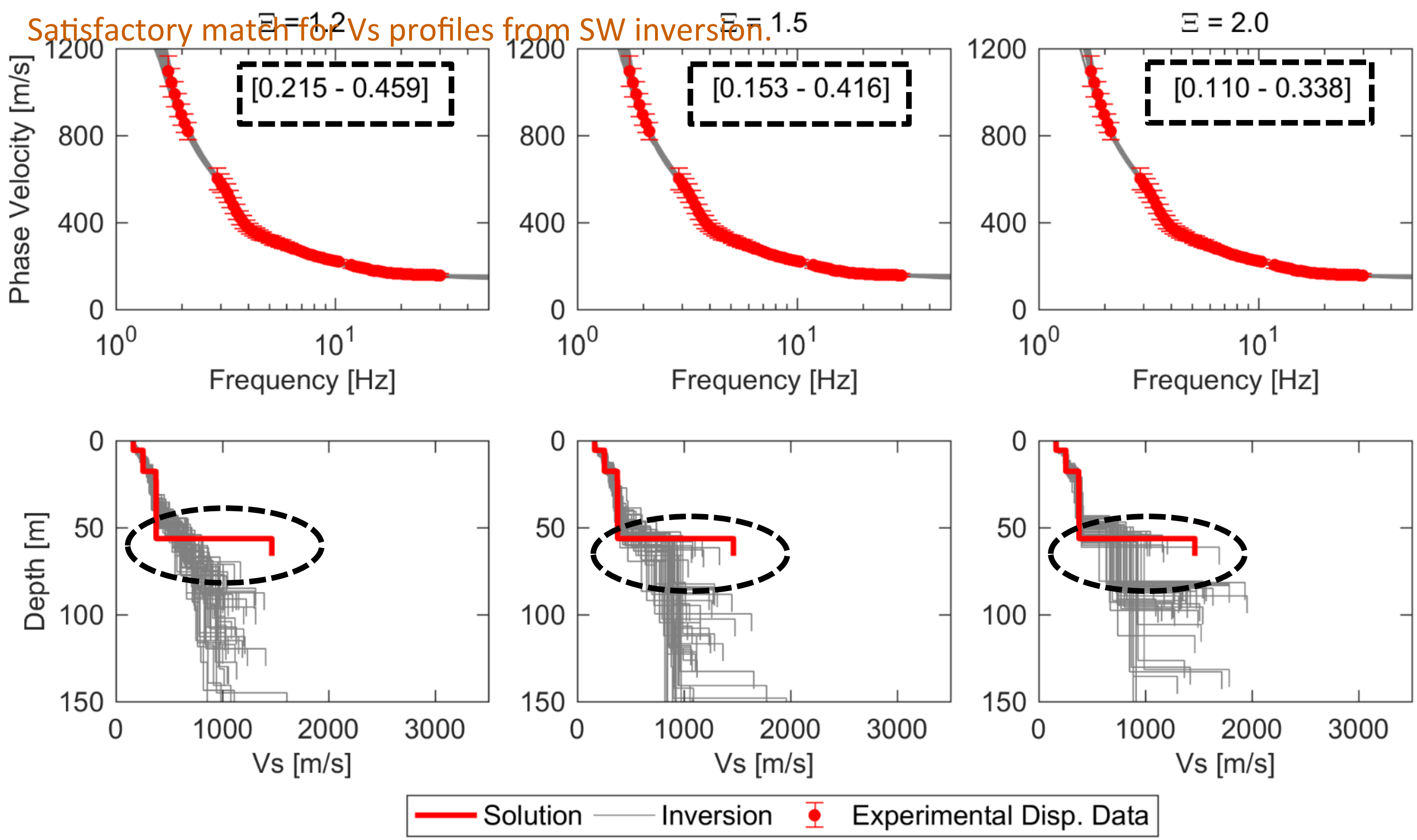
InterPacific Site 4

- Semi-synthetic site associated with InterPacific (Intercomparison of methods for site parameter and velocity profile characterization) Project.
- True/solution Vs profile was available.
- Analysts were asked to invert experimental dispersion data and submit "best" Vs profile.
- After submission of results, analysts were provided with true/solution profile and experimental H/V curve.



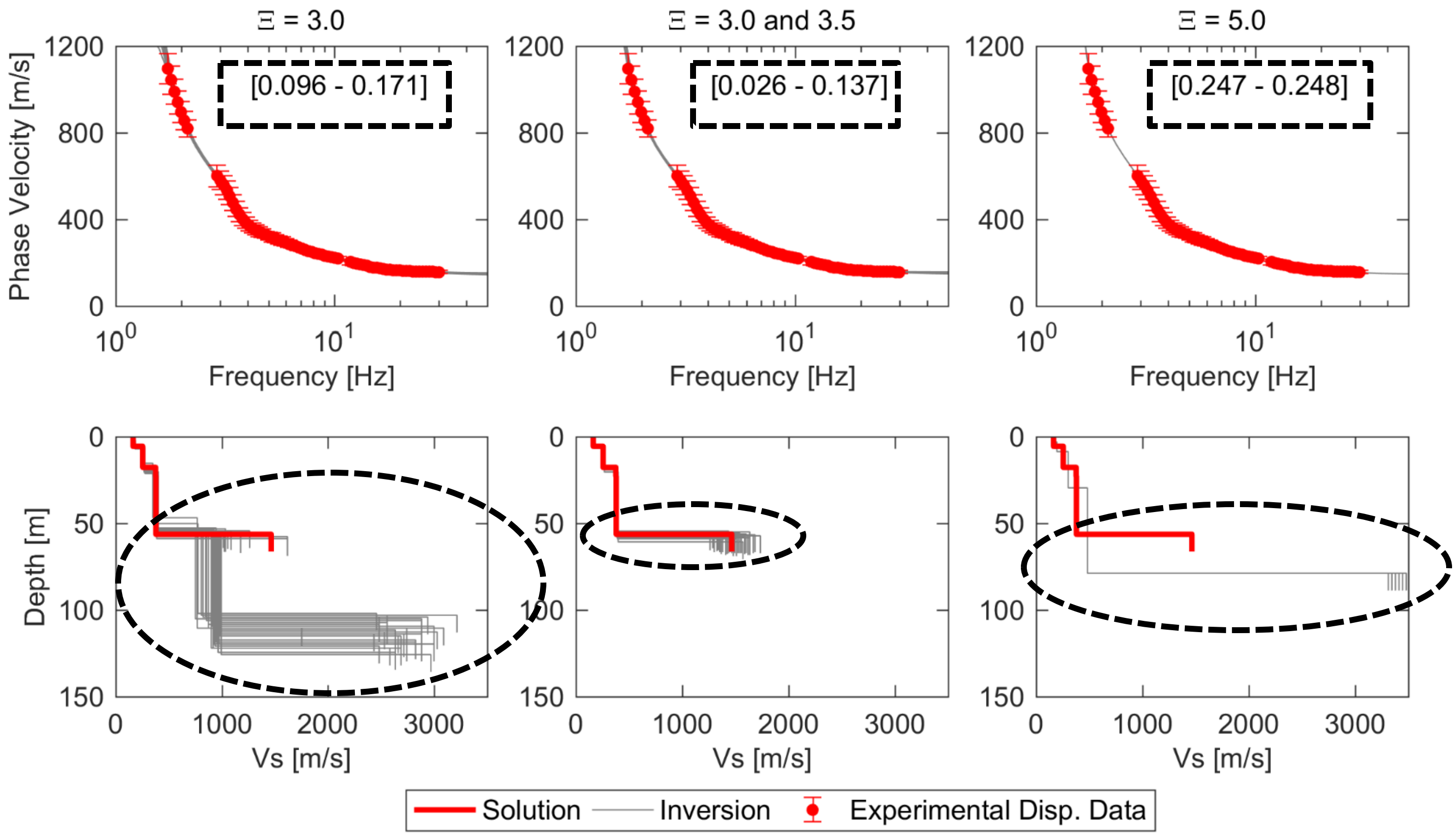
Inversion Results (Ξ of 1.2, 1.5, and 2)

- Vs parameterizations systematically explored using "layering ratio" approach (Cox and Teague 2016)
- Not capturing significant velocity contrasts seen in solution.
- Theoretical dispersion curves (DC) vs experimental dispersion data
  - Satisfactory match for Vs profiles from SW inversion.



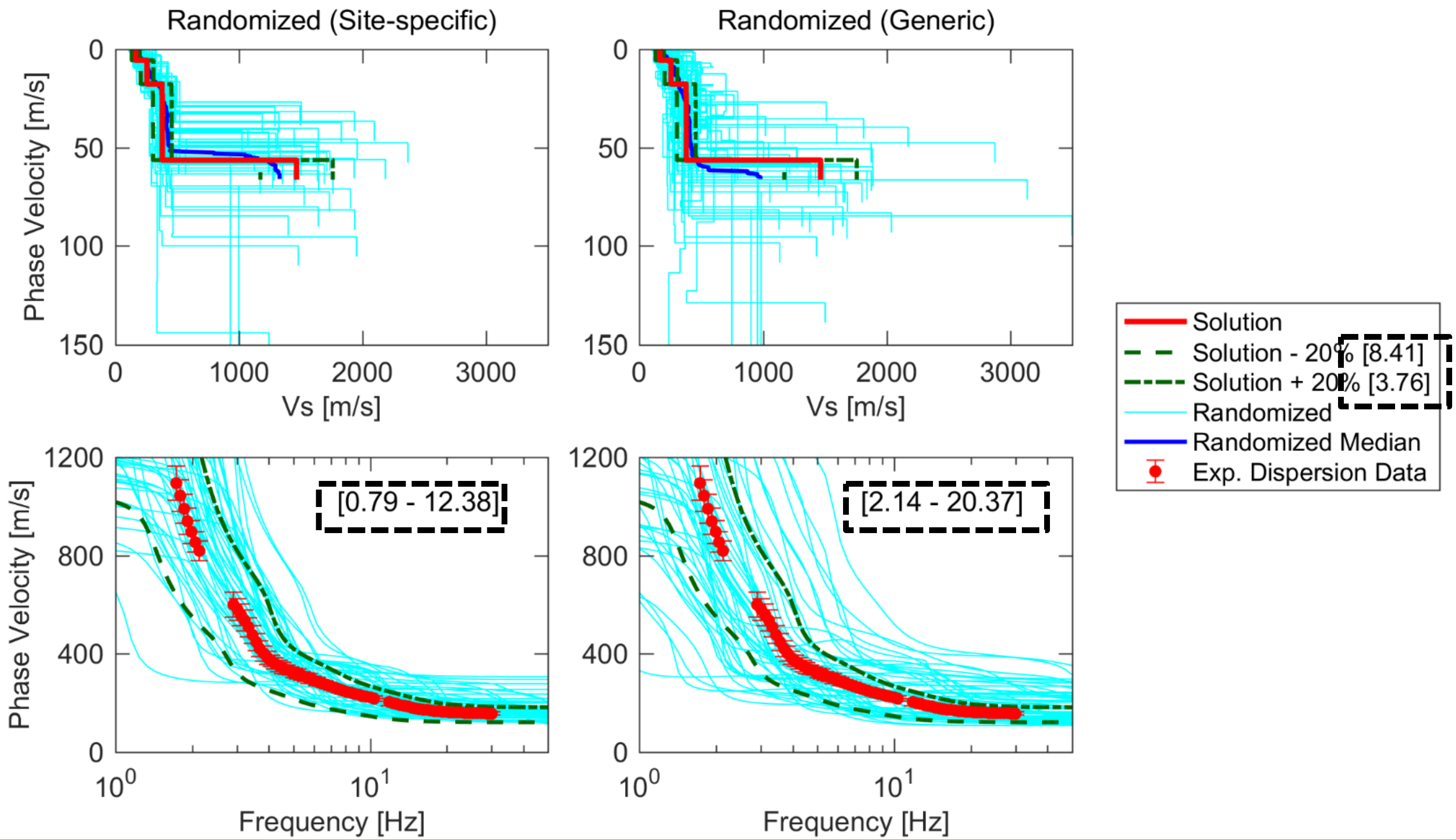
Inversion Results (Ξ of 3.0, 3.5 and 5)

- Variability in Vs decreases with number of layers (increasing Ξ) for a given number of trial earth models. Vs profiles show larger impedance contrasts.
- Ξ of 3.5 and 3.5*: Vs profiles match solution remarkably well. Misfits up to an order of magnitude lower than all other Ξ.
- Depth to bedrock varies considerably.

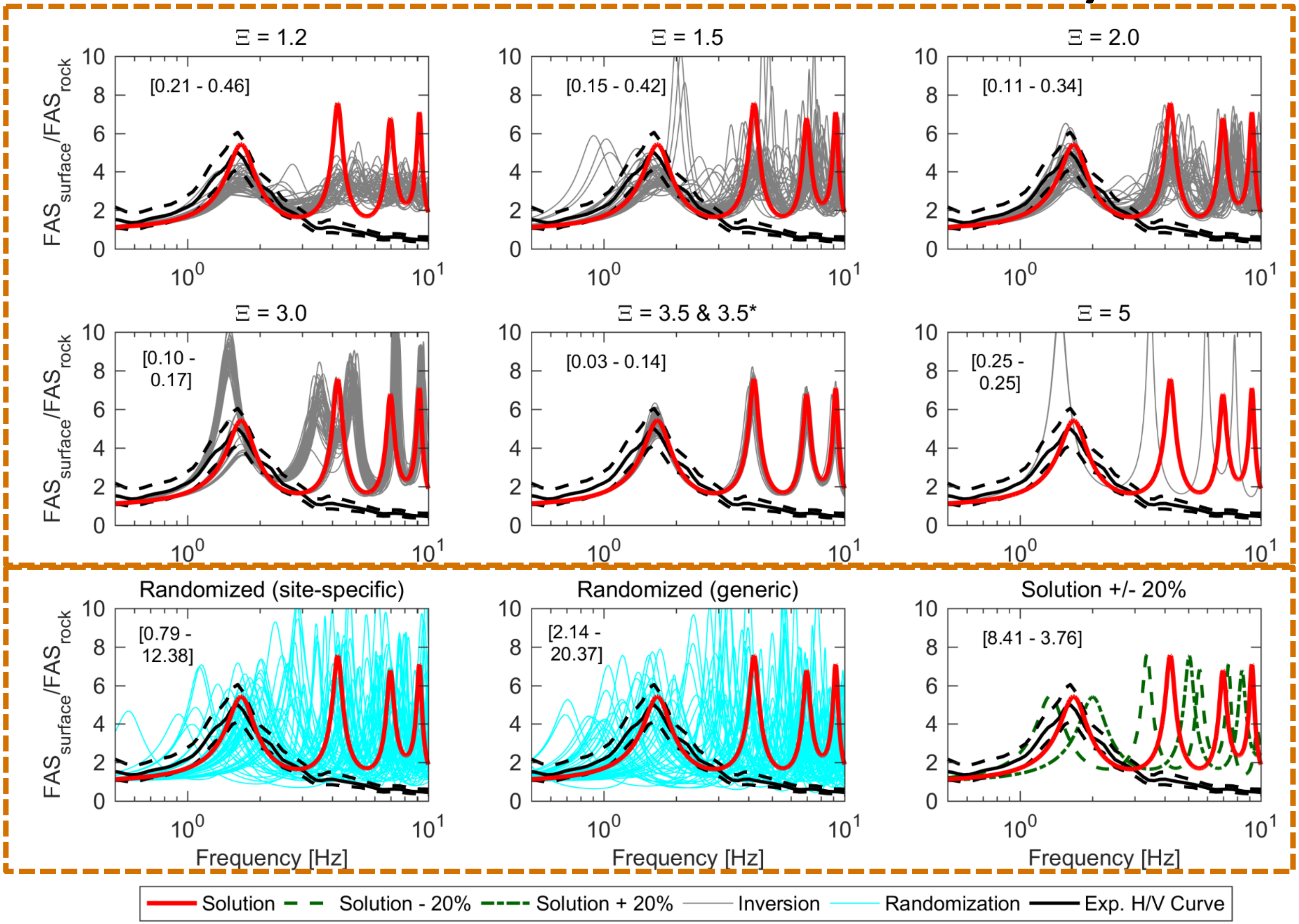


Randomized and Upper-/Lower-Range Base Case Vs Profiles

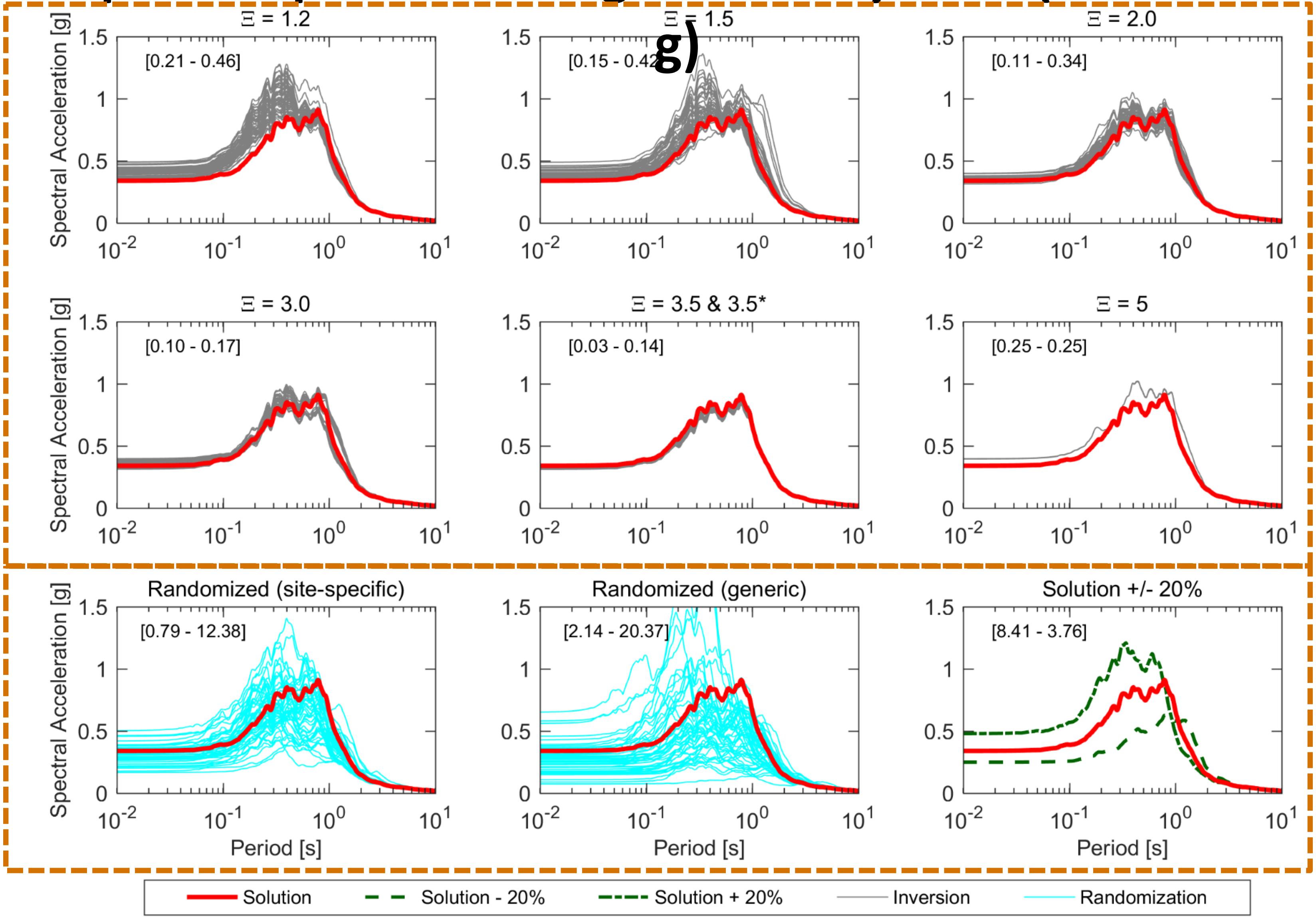
- Statistically-based, randomized Vs profiles generated using Toro (1995) randomization model
- Upper/lower-range base cases developed by applying epistemic uncertainty factor of 20% to solution Vs profile
- Extreme variability in randomized Vs profiles
- Misfit values 10 to 100 times higher than those associated with the inversion



Linear-Elastic Transfer Functions and the H/V Curve



Response Spectra for High Intensity GMs (PGA of 0.30 g)



Conclusions

- Non-unique Vs profiles developed from surface wave inversion exhibited considerable differences. Only one trial parameterization yielded Vs profiles that were very consistent with the true solution at all depths.
- Non-unique Vs profiles derived directly from inversion generally produced similar site response estimates. These estimates were in excellent agreement with the solution and exhibit relatively low variability.
- Upper/lower base-case profiles (e.g., mean +/- 20%) commonly utilized to account for epistemic uncertainty did not fit the experimental dispersion data well and were found to significantly over/under-predict spectral accelerations (SA) for high intensity input GMs.
- Statistically-based, randomly generated Vs profiles commonly utilized to account for aleatory variability also failed to fit the experimental dispersion data or H/V curve well and were found to yield inaccurate and highly-variable SA predictions, although the inclusion of site-specific randomization model parameters derived from the surface wave inversion Vs profiles improved results.
- Non-unique Vs profiles derived from surface wave inversion, when obtained properly by systematically exploring various layering parameterizations, provide a means for accounting for Vs uncertainty in a rational manner.

References

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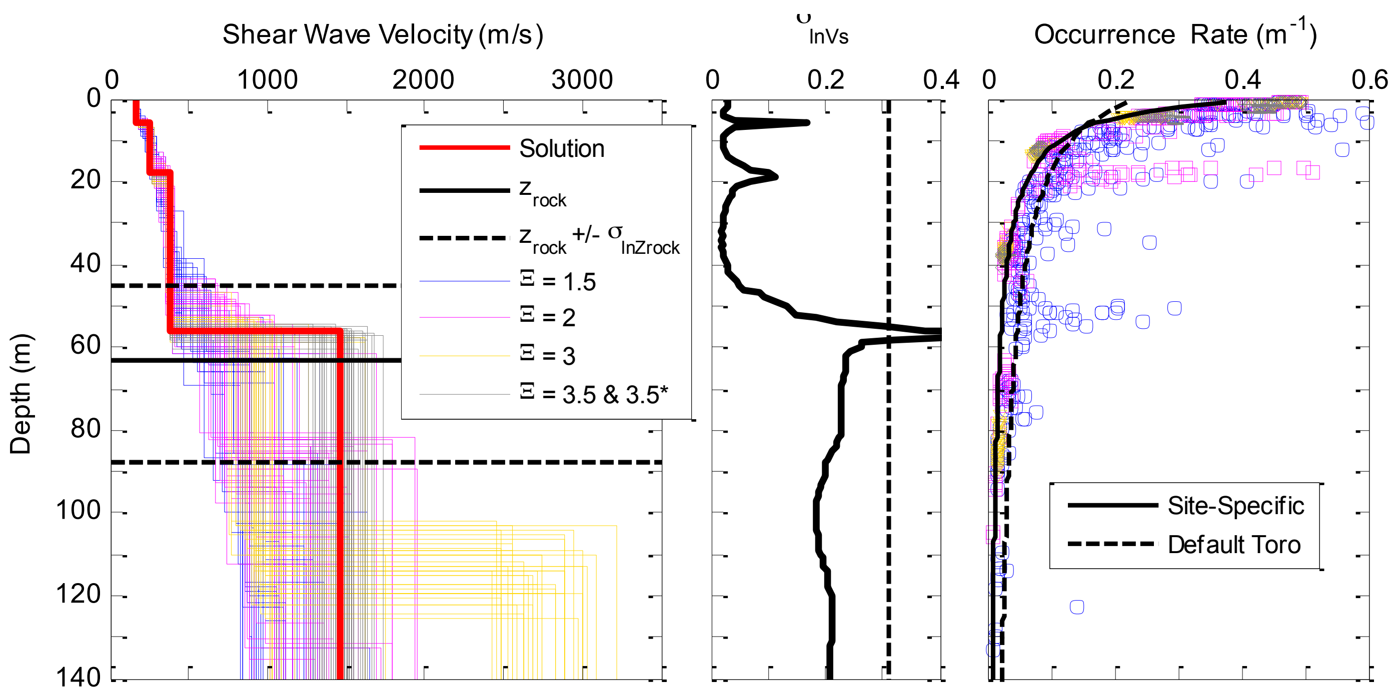
Statistically-Based, Randomly Generated Vs Profiles

- Toro (1995) randomization model used to generate randomized Vs profiles
- Toro model operates three categories of parameters:
    1) Vs statistical parameters
    2) Layering Parameters
    3) Depth to bedrock parameters
- Two sets of randomized Vs profiles developed
    1) Site-specific statistics used to develop the parameters
    2) Default/recommended parameters.



Equivalent Linear Site Response Analyses

- Input rock ground motions (GMs)
  - Target spectrum developed using Boore and Atkinson (2008) ground motion prediction equation
    - M_W of 7.5, R_{JB} of 15 km, and V_{S30} of 1300 m/s
    - Eight GMs chosen from library of 40 candidate GMs
  - GMs re-scaled in order to investigate influence of EQ intensity
    - "Low-intensity": average PGA of 0.05 g
    - "High-intensity": average PGA of 0.30 g
- Analyses performed using Matlab codes developed at UT
  - Sub-divided major layers so that numerical filtering below 50 Hz would not be problematic
- G/G_{max} and damping relationship proposed by Darendeli (2001)
  - All layers were assumed non-plastic (PI = 0) and normally consolidated (OCR = 1)