A Probabilistic Approach to Site-Specific, Hazard-Consistent Vertical-to-Horizontal Spectral Ratio Model

Presented at

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Outline

- Motivation
- Background
- Proposed methodology
- Case study
- Summary

Motivation

Vertical design spectra needed for

- Critical structures such as NPPs and dams
- Building with long-span floors
- Floors supporting sensitive equipment
- Industrial facilities supporting massive equipment
- Near-fault ordinary bridge, etc.

Approaches to developing vertical design spectra

Direct approach from vertical hazard

- Theoretically sound
- Lack of vertical GMPE
- Inconsistent controlling scenarios between V and H

Indirect approach scaling horizontal spectra using a V/H model

- Assume the same deaggregation for H and V
- Implicitly presume equal aleatory uncertainty in H and V
- Can be applied to UHS, CMS, scenario spectra and even horizontal hazard curve
- Dominate the current practice

V/H models

- Code and regulation based

  NUREG/CR-6728, Eurocode 8, ASCE 4-98, NEHRP

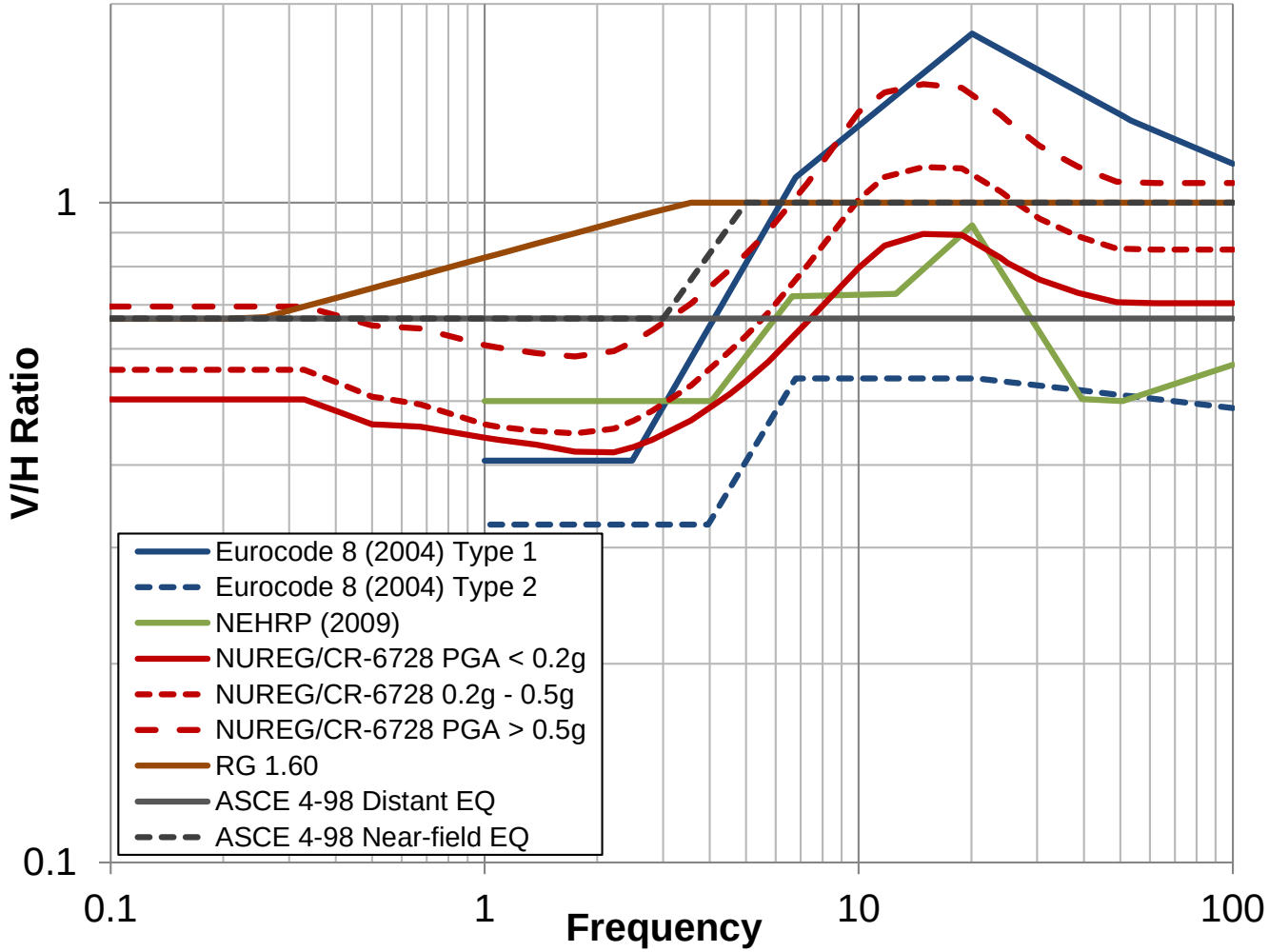
- Separate predictions of spectral ordinates

  Abrahamson and Silva, 1997;
  Bozorgnia and Campbell, 2004; NGA-West 2

- Direct predictions of V/H ratios

  Gulerce and Abrahamson, 2011; Bommer et al., 2011;
  Edwards et al., 2011

V/H models from codes and regulations
(Western North America condition)



Features of the proposed approach

- Considers the correlation between H and V/H
- Analogous to Approach 3 for site amplification (e.g., NUREG/CR-6728 or SPID)
- Compatible with horizontal component of hazard in terms of uncertainty considerations
- Application in the framework of vector-valued PSHA
- Relies on site-specific horizontal amplification studies

Procedures of the proposed approach

1) Develop horizontal soil hazard
2) Estimate the mean and stdev. for H per deaggregation earthquakes per AFE
3) Estimate mean and stdev. for V/H per deaggregation earthquakes per AFE
4) Develop the correlation coefficients between H and V/H
5) Compute conditional mean and conditional standard deviation of V/H ratio based on the correlation model
6) Apply the convolution between V/H and H to get vertical soil hazard and vertical design spectra for certain frequencies
7) Compute the V/H ratios and obtain the V/H curve through extrapolation

Key Formulations

$$\lambda(a^V) = \sum_i \sum_j \sum_k P(R > \frac{a^V}{a_k^H} | M_i, R_j, a_k^H)\, \lambda'(M_i, R_j, a_k^H)\, \Delta a_k^H$$

$$P\left(R > \frac{a^V}{a^H} \middle| a^H\right) = 1 - \Phi\left[\frac{\ln\left(\frac{a^V}{a^H}\right) - \left(\mu_{\ln R} + \rho_{\ln R, \ln H}\sigma_{\ln R}\epsilon_{\ln H}\right)}{\sigma_{\ln R}\sqrt{1 - \rho_{\ln R, \ln H}^2}}\right]$$

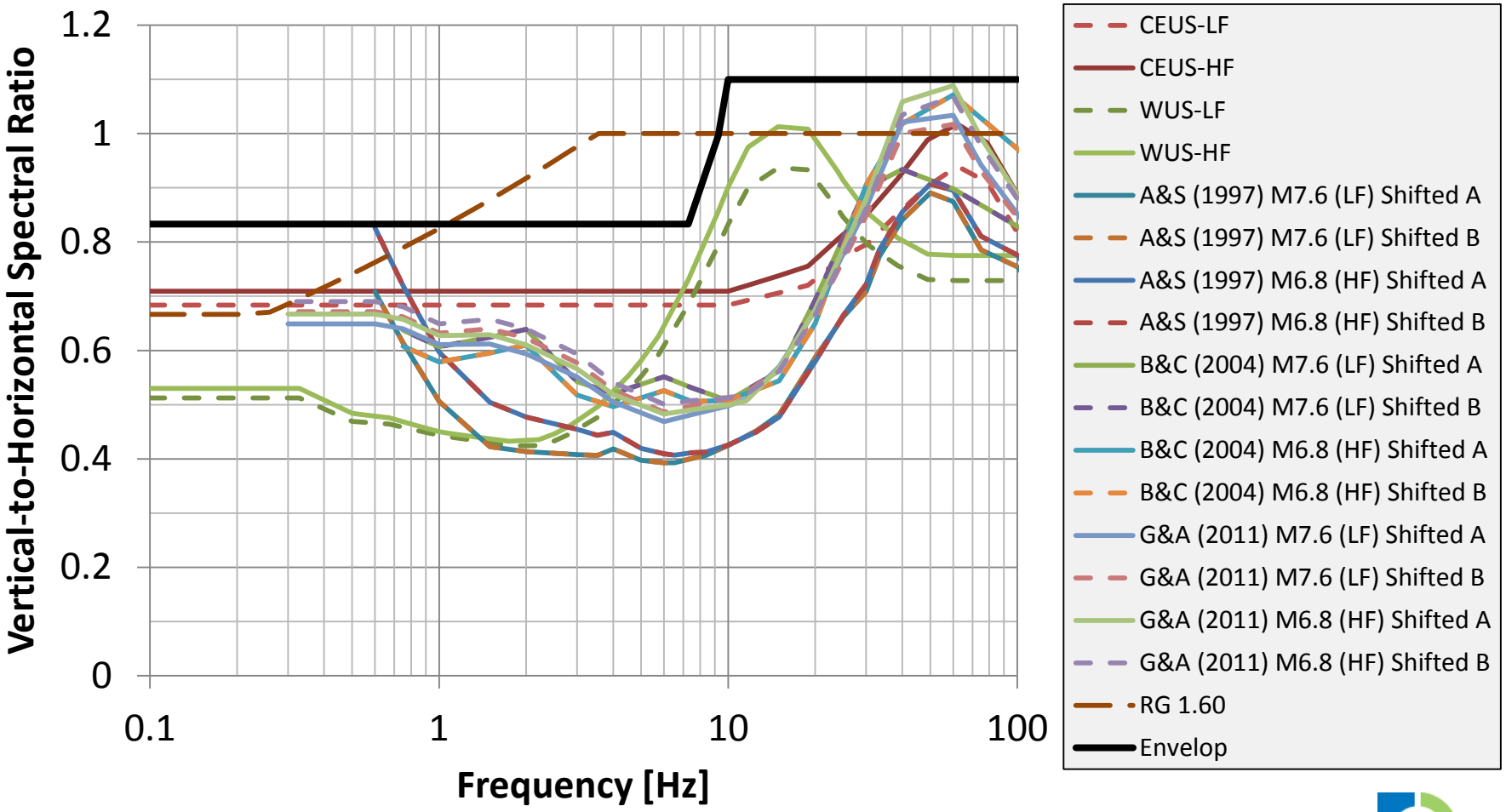
$$\epsilon_{\ln H} = \frac{\ln(a^H) - \mu_{\ln H}}{\sigma_{\ln H}}$$

$$\mu_{\ln H} = \mu_{\ln \mathrm{H_0}} + \mu_{\ln \mathrm{AF}} \qquad \sigma_{\ln H} = \sqrt{(c_1 + 1)^2 \sigma_{\ln H_0}^2 + \sigma_{\ln AF}^2}$$

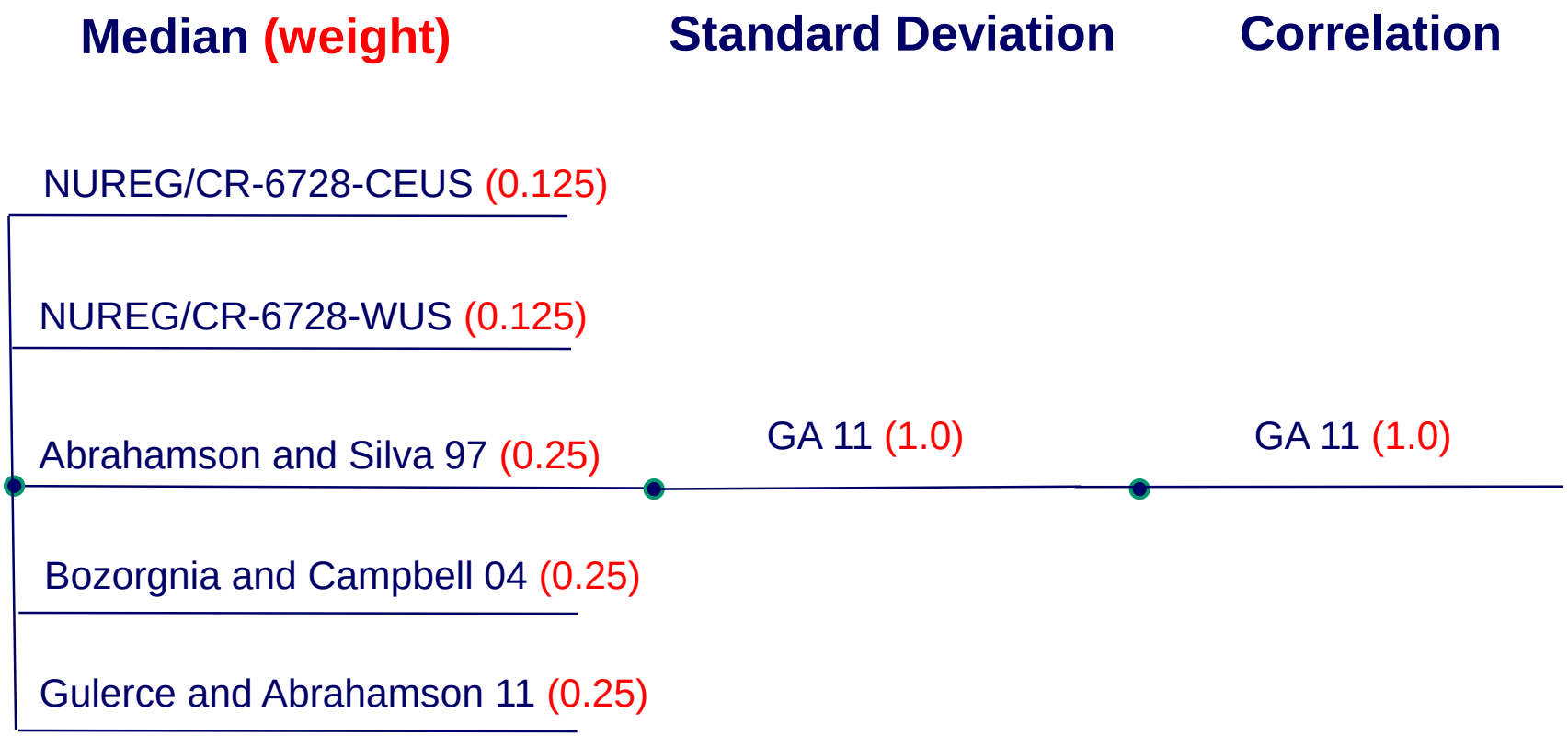
Case Study: Background

- An anonymous site in central eastern US (Vs30 = 650~700 m/sec)
- Source characterization model: CEUS SSC
- Ground motion model: EPRI (2004; 2006)
- Horizontal site amplification: RVT-based equivalent-linear approach
- V/H model: deterministic versus probabilistic

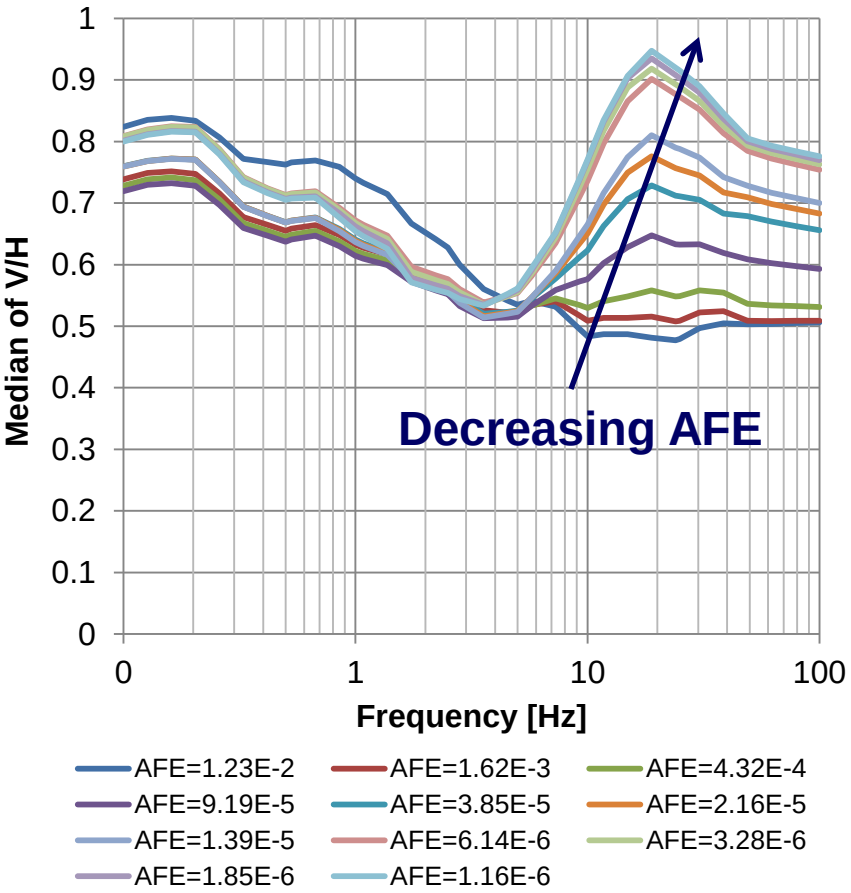
Case Study: Deterministic V/H Ratio

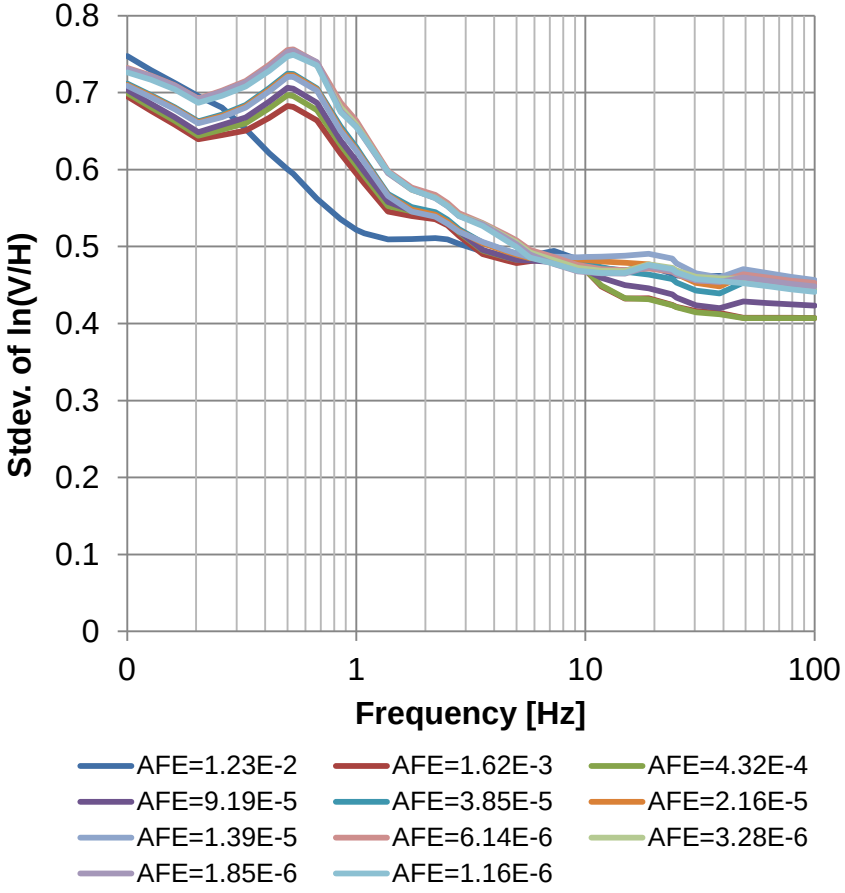


Case study: logic tree for Probabilistic V/H model

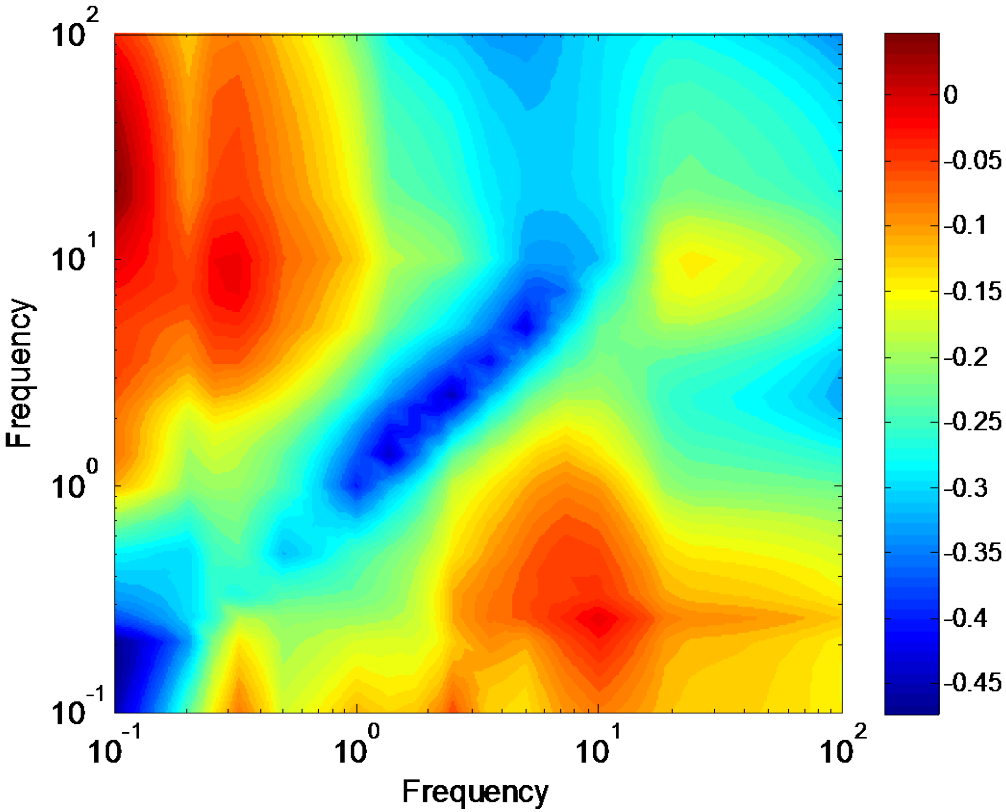


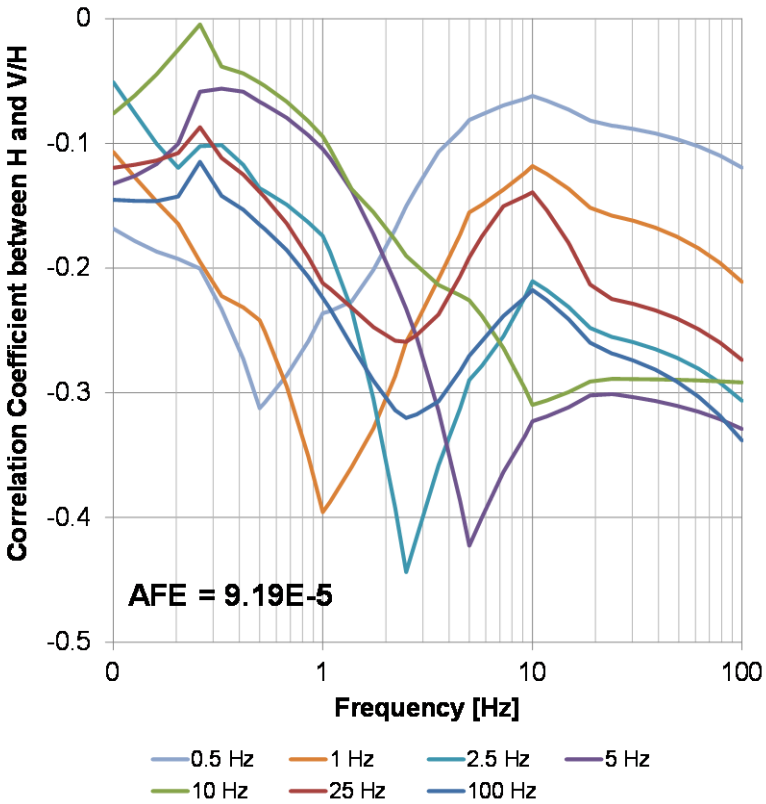
Case study: Total median and logarithmic standard deviation



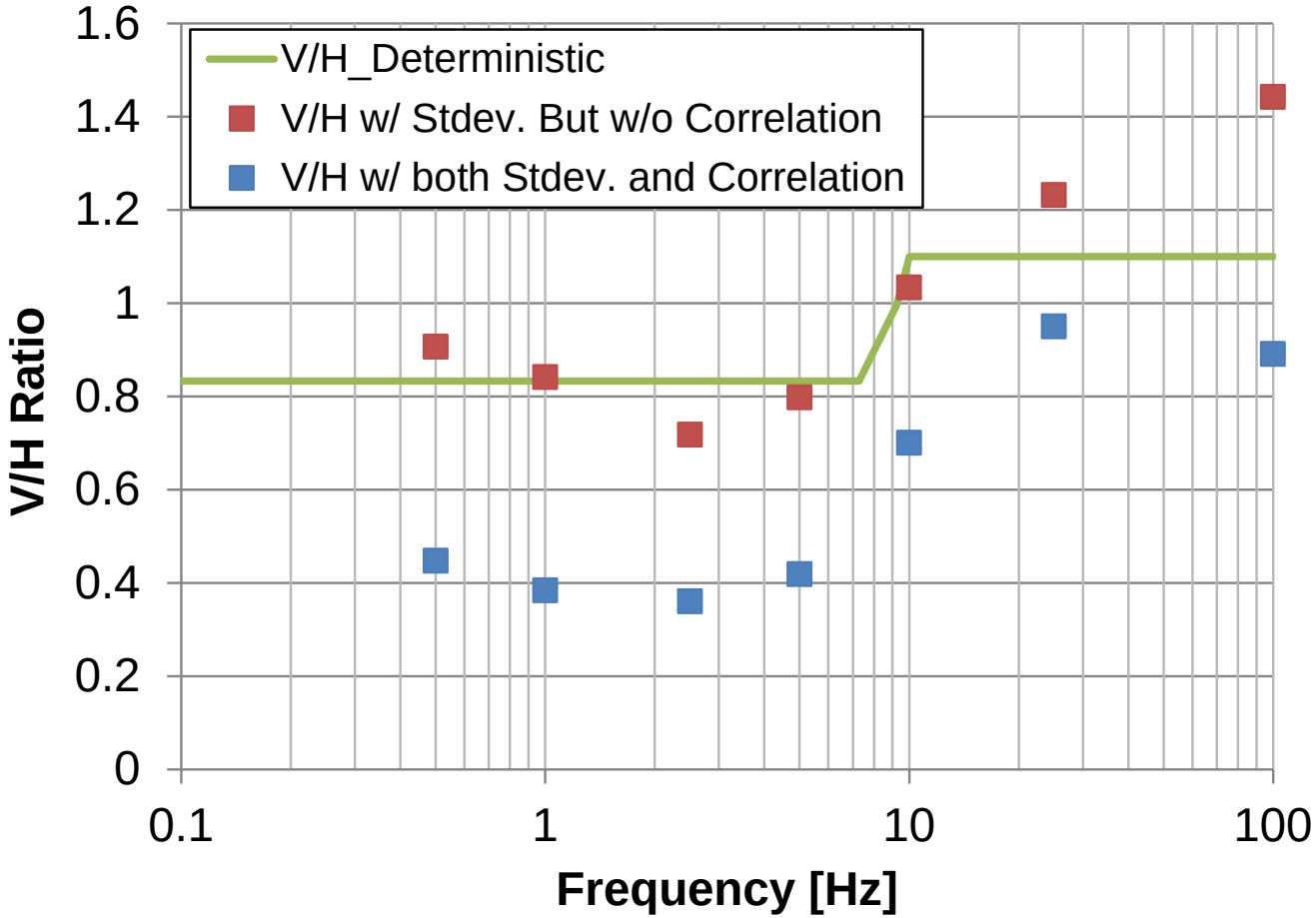


Representative correlation coefficient (AFE = 9.19E-5)

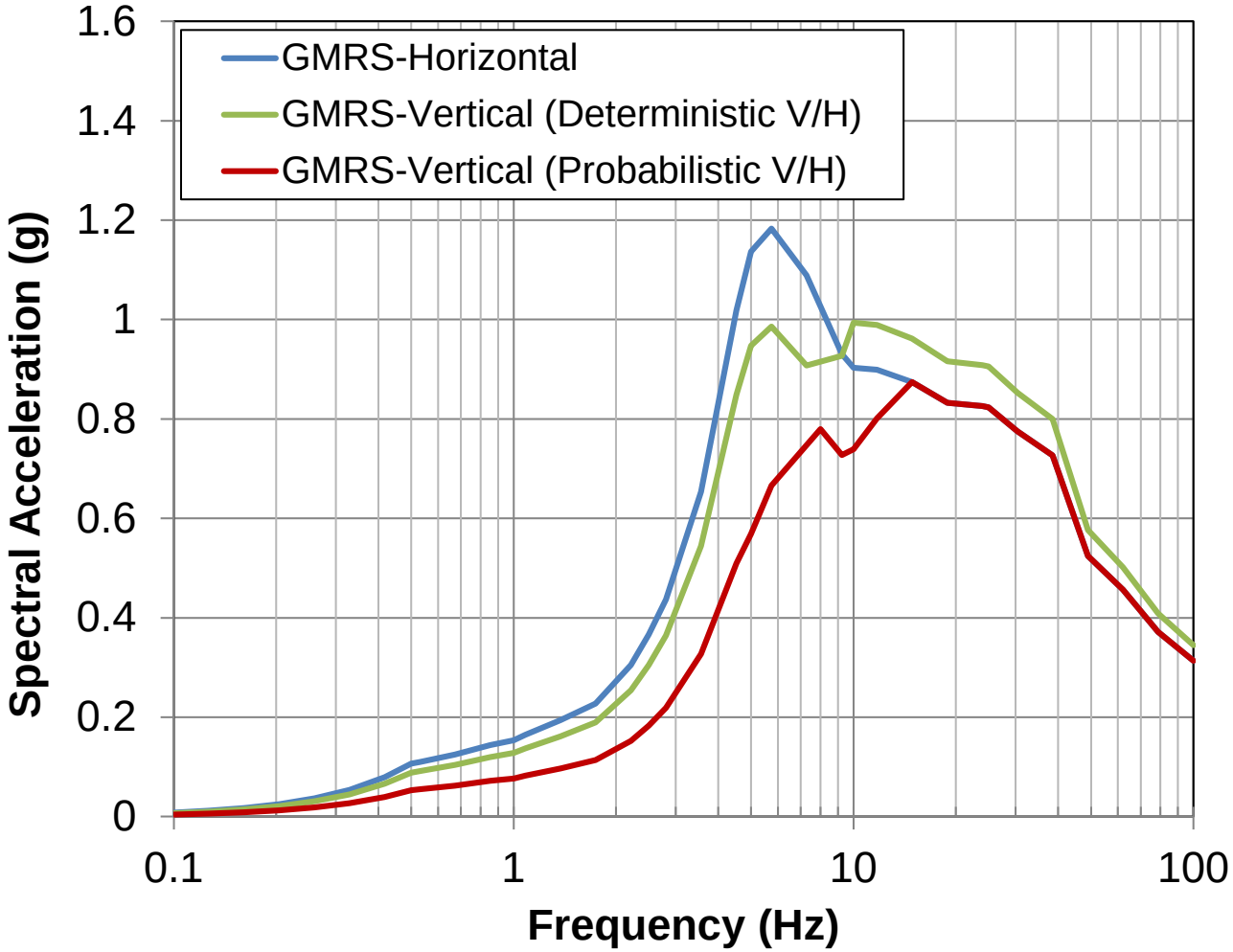




Comparison of V/H ratio



Comparison of GMRS



Implementation Issues

- Only few sigma models (Bozorgnia and Campbell 2004; Bommer et al. 2011, Gulerce and Abrahamson, 2011; Edwards et al., 2011) and one correlation model (Gulerce and Abrahamson, 2011) available currently

- Three hierarchies for implementation
  1) Convolve V/H ratios with horizontal hazard
  2) Convolve V/H ratios with deaggregated horizontal hazard
  3) Vertical Median and sigma corrected from horizontal GMPE (similar to Vs-kappa correction)

Summary

The proposed probabilistic approach

- Compatible with the approach to horizontal hazard
- Epistemic and aleatory uncertainties incorporated
- Site-specific and hazard consistent
- May reduce vertical design spectra w/o non-conservative assumptions
- Subject to the lack of standard deviation and correlation model
- Some implementation details

Thank you for your attention!

Questions?