3D Seismic Site Response with Soil Heterogeneity and Wave Scattering

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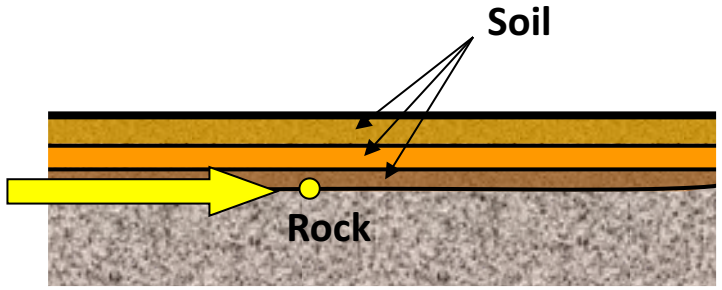
Conventional 1D Site Response Idealisations

Apply input motion

1-D analysis



Kramer and Arduino

1D = Waves propagate in only one direction (vertically)

Homogenous, horizontally layered system

Typically only SH waves (vertically propagating shear waves)

Reality

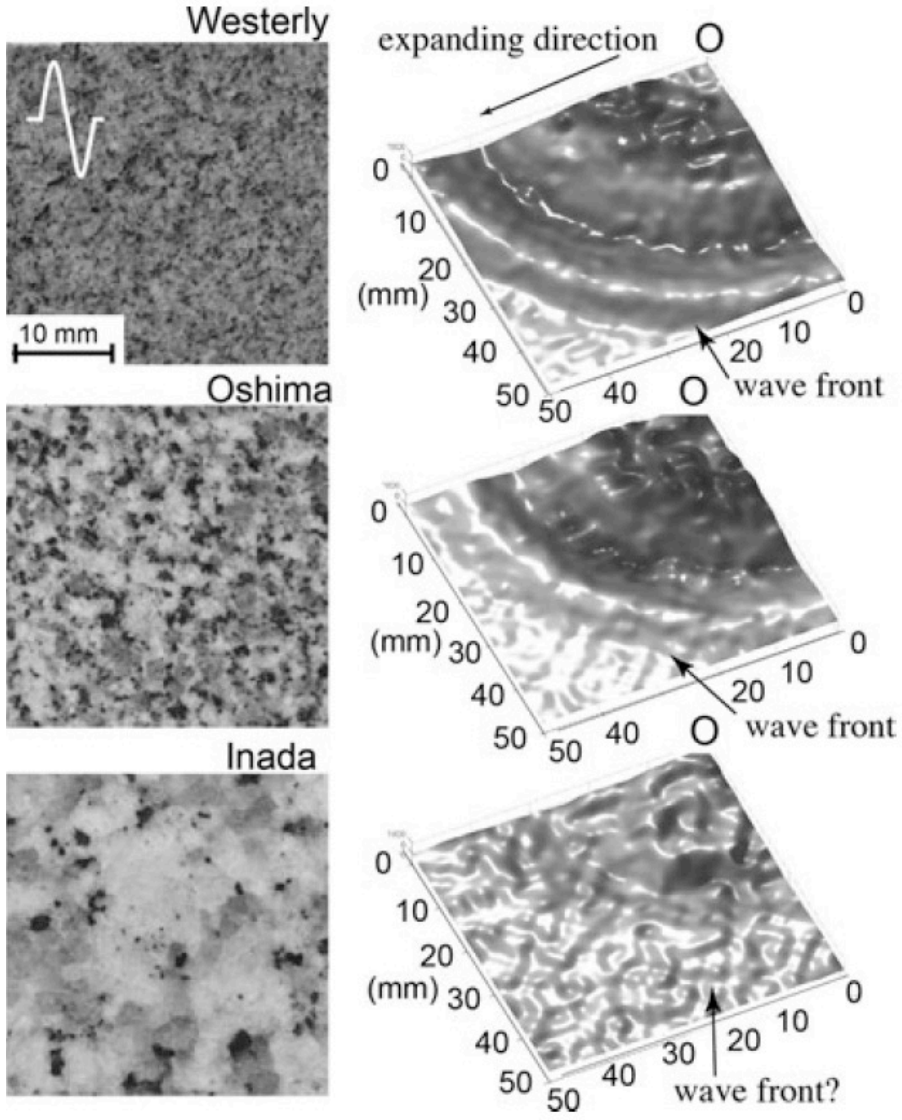
- Soil Heterogeneity
- 3D wavefield
- 3D soil response

Can’t capture wave scattering in 1D analysis

Heterogeneities Cause Wave Scattering

- High frequency waves are scattered by heterogeneities

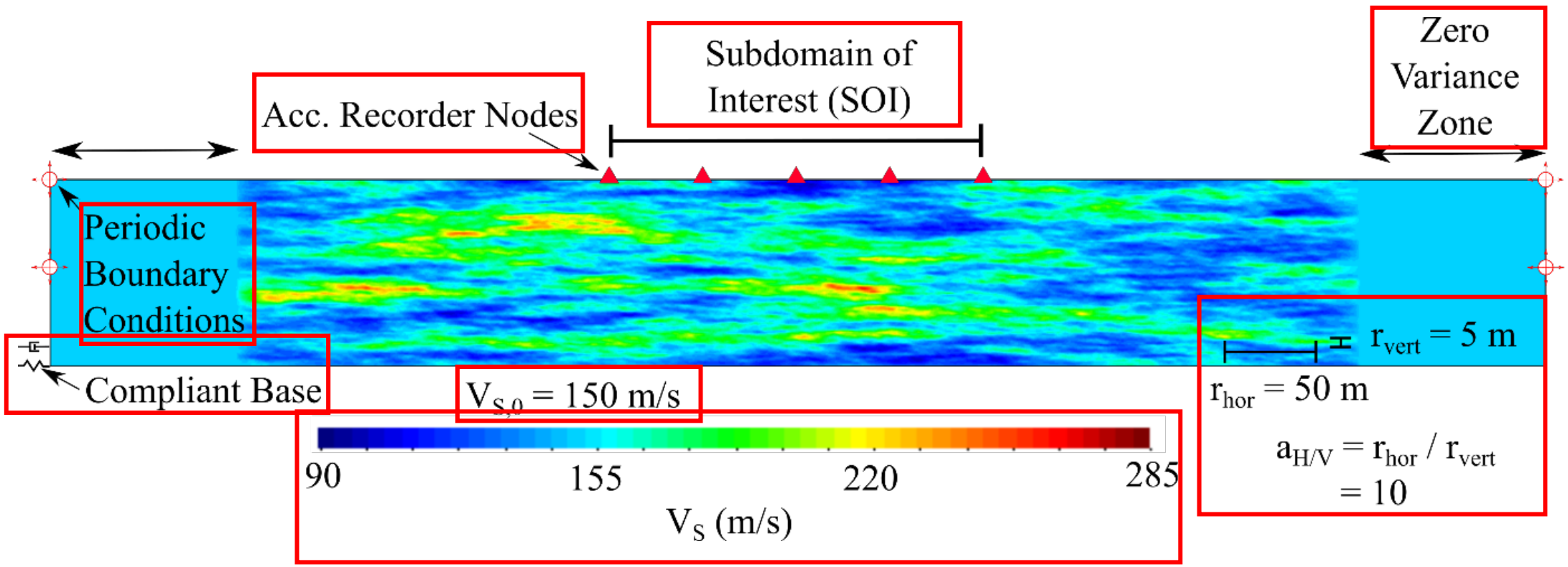
- Scattering highly dependent on:
  - Frequency content of motion
  - Length scale of heterogeneities



Sivaji et al. (2002) from Sato et al. (2012)

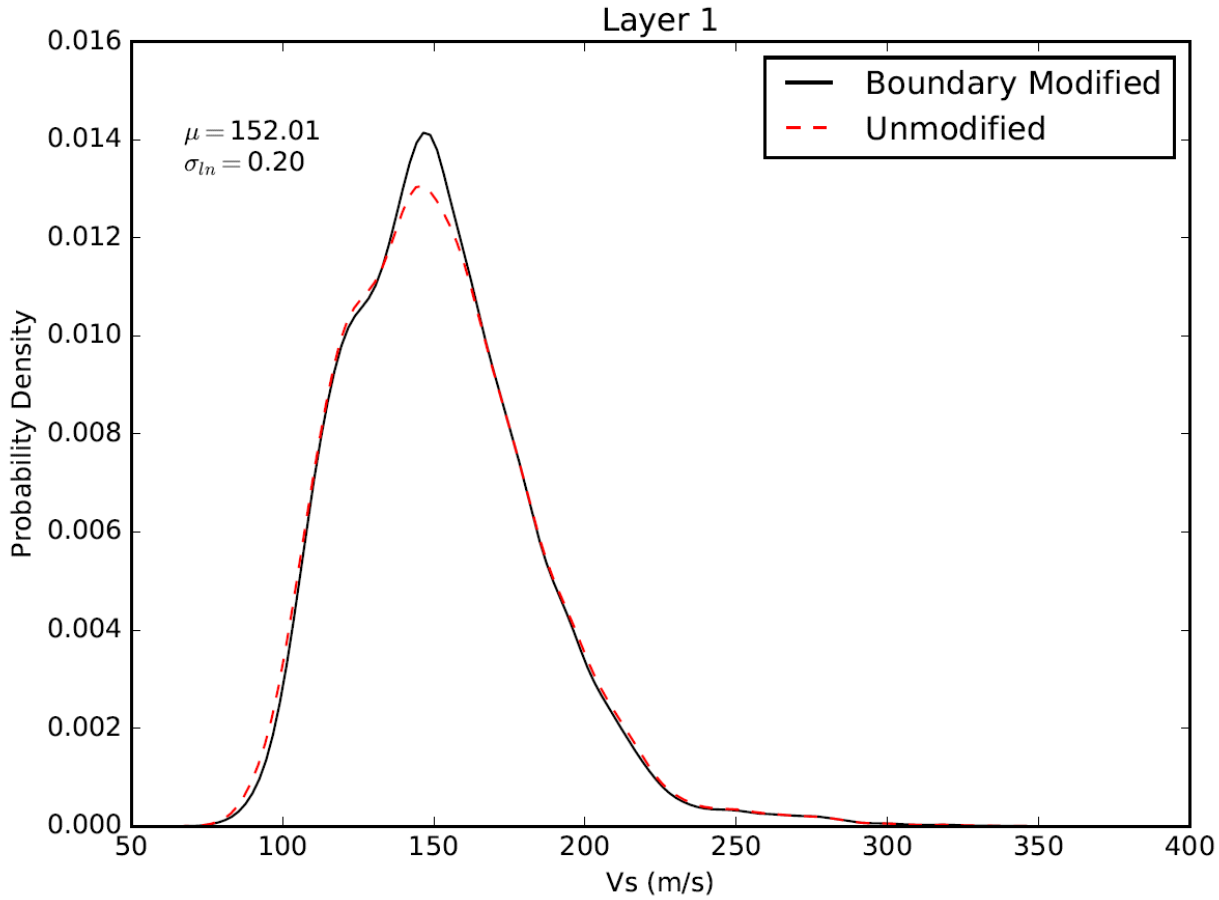
Site Response Methodology

- FEM analysis in OpenSees



Random Field Generation

- Anisotropic spatially correlated random field
  - Python: GSTools
- Exponential correlation function
  - von Kármán model with ν = 0.5
- V_S lognormally distributed
  - μ_{lnVs} (or median $V_{S,0}$) and σ_{lnVs}

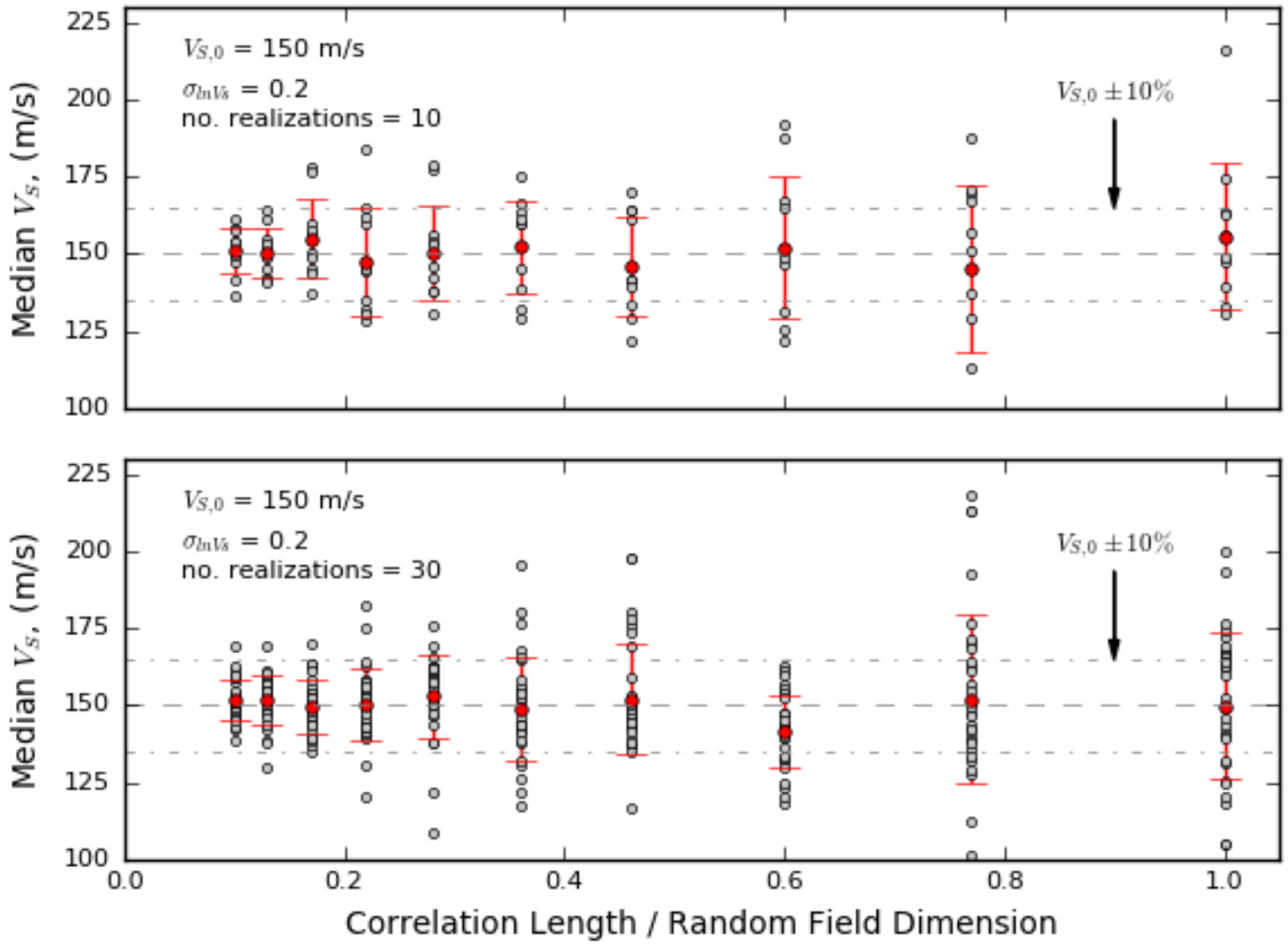


Sensitivity Analysis

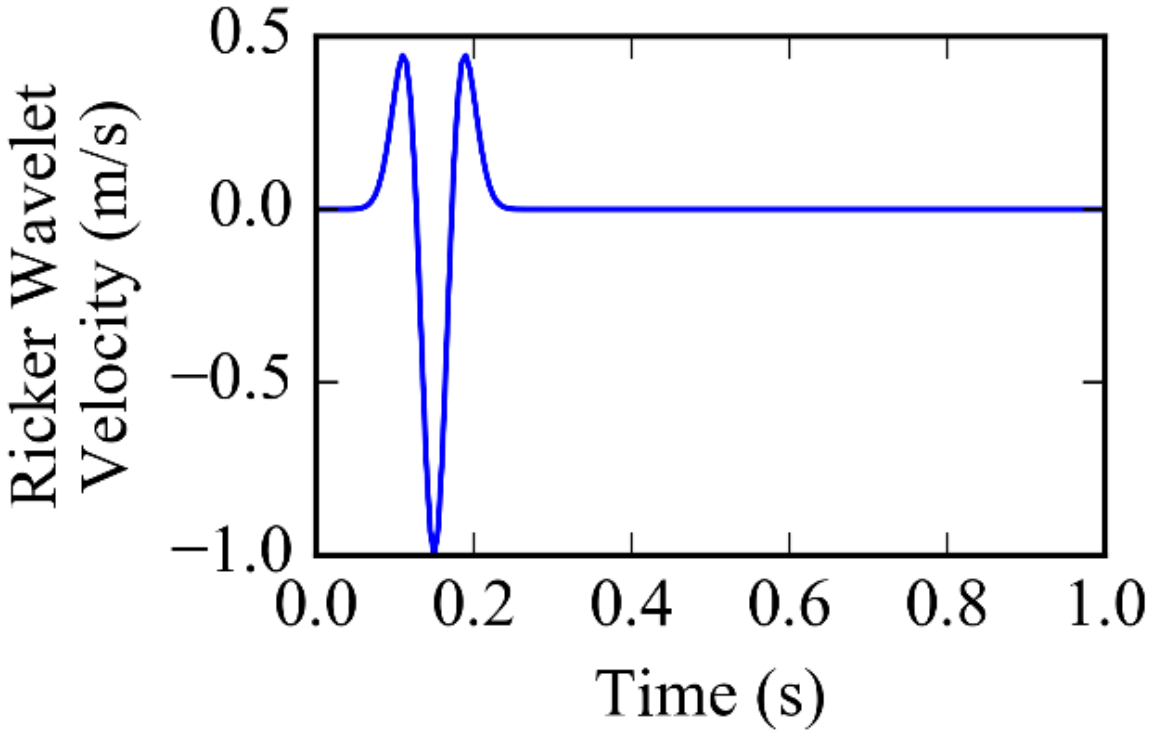
Parameter Name	Symbol	Values used in Sensitivity Analysis
Median Shear Wave Velocity	$V_{S,0}$	150, 400 m/s
Standard Deviation of ln(V_S)	σ_{lnVs}	0.10, 0.20, 0.35
Horizontal Correlation Length	r_{hor}	25, 50, 75, 100 m
Anisotropy Factor	$a_{H/V}$	1, 5, 10, 20

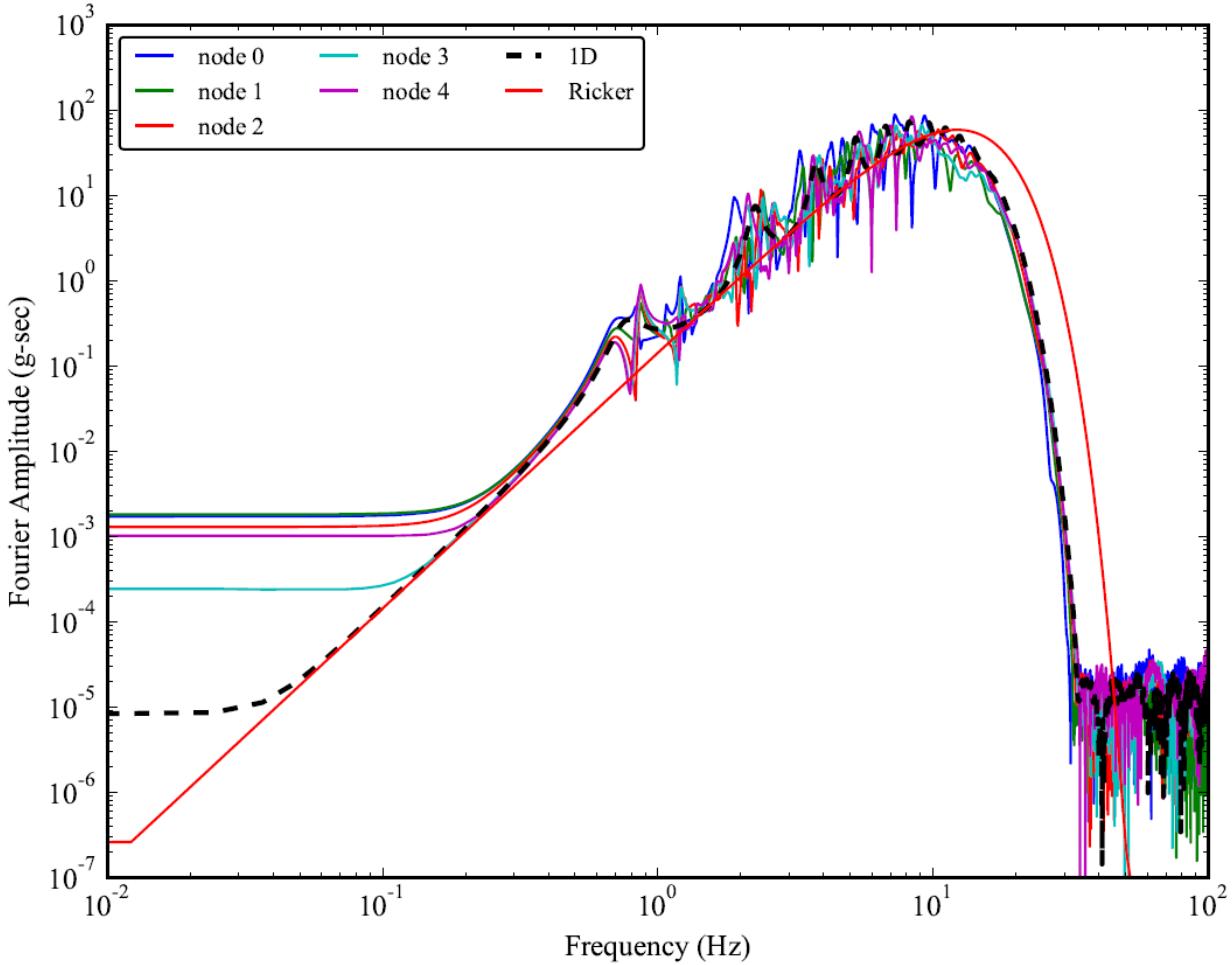
x 10 realisations/permutation = 960 analyses

Random Fields: Statistics and Dimensions

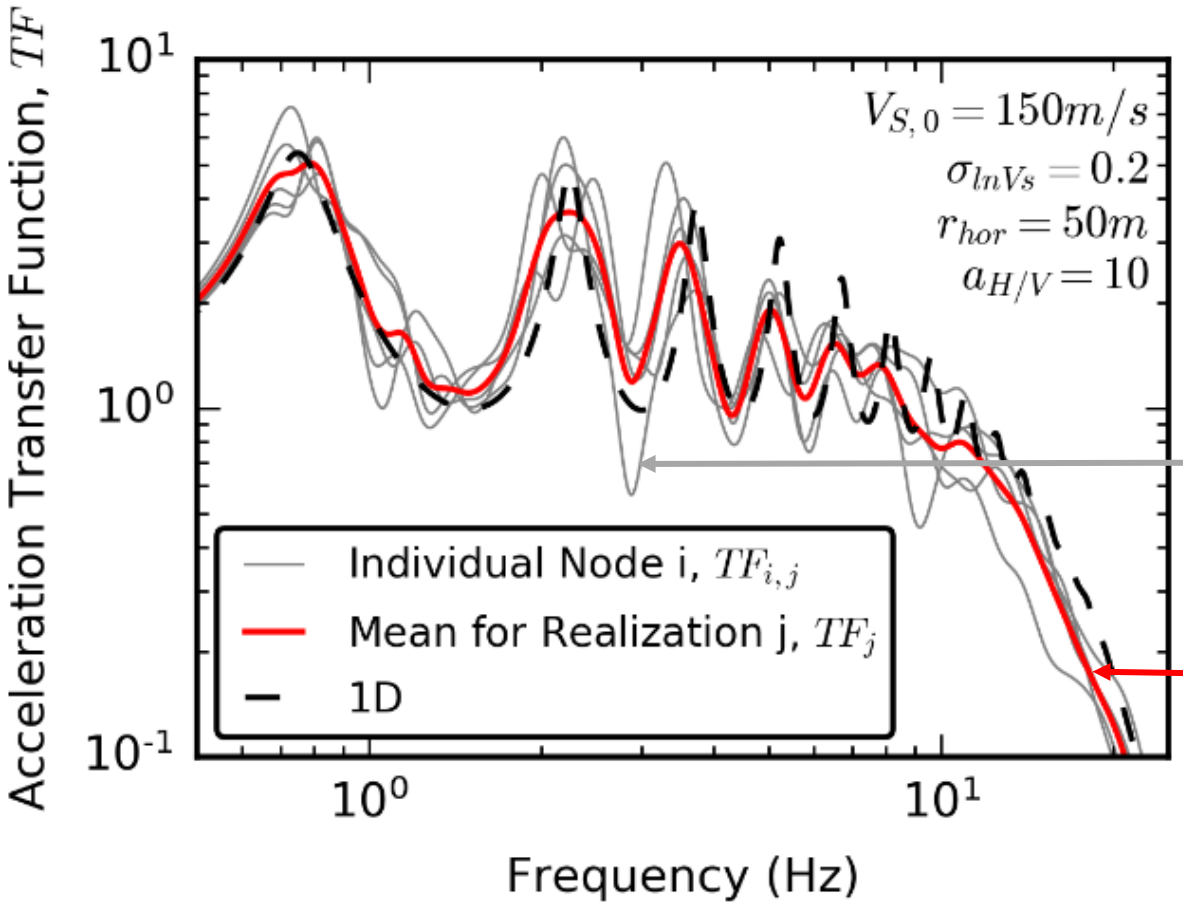


Input Motion: Ricker Wavelet

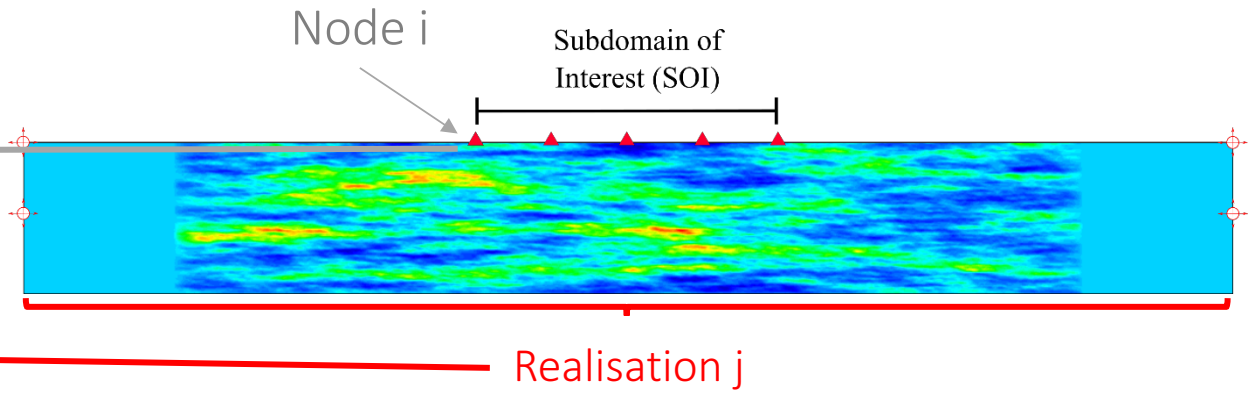




Response at an Individual Node



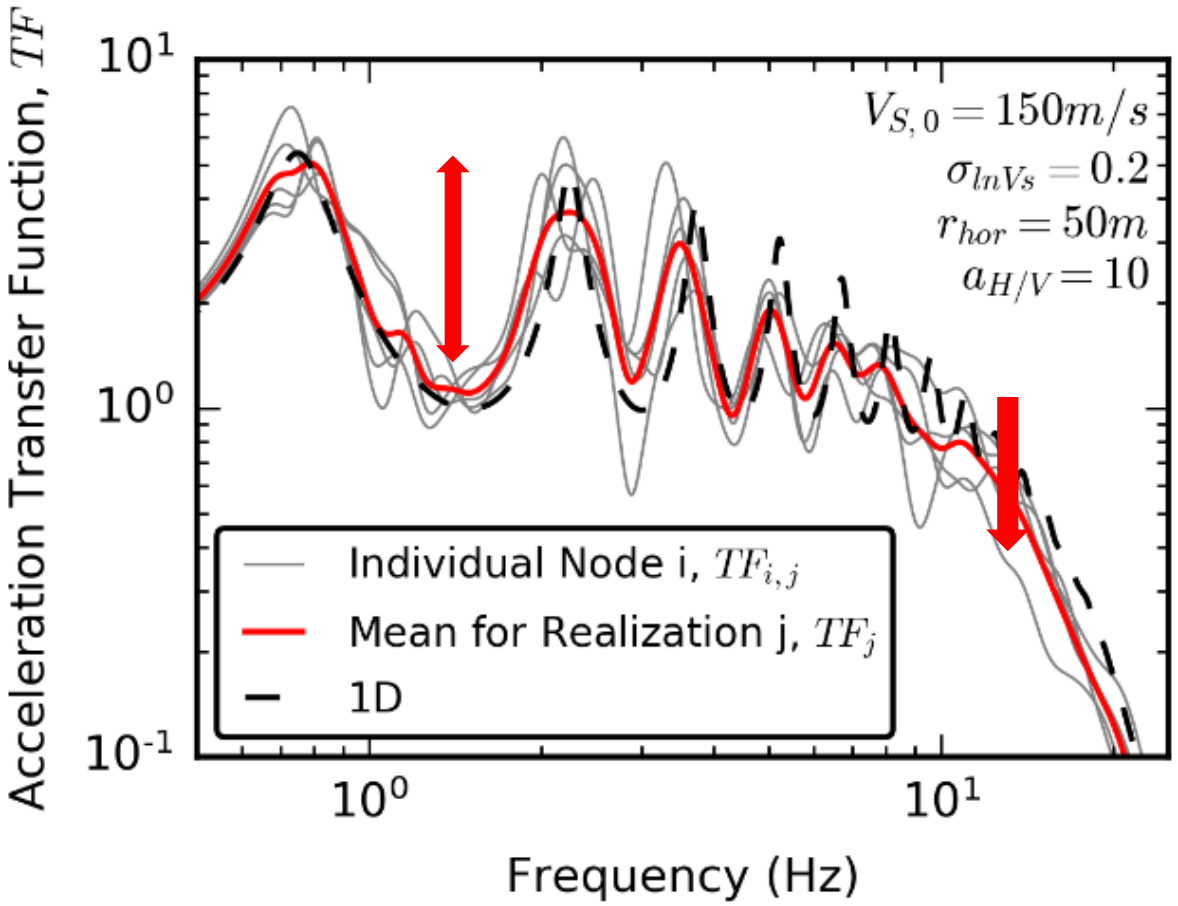
$$\text{TF} = \frac{Fourier\ Spectrum\ Ground\ Surface}{Fourier\ Spectrum\ Base}$$



Notation:

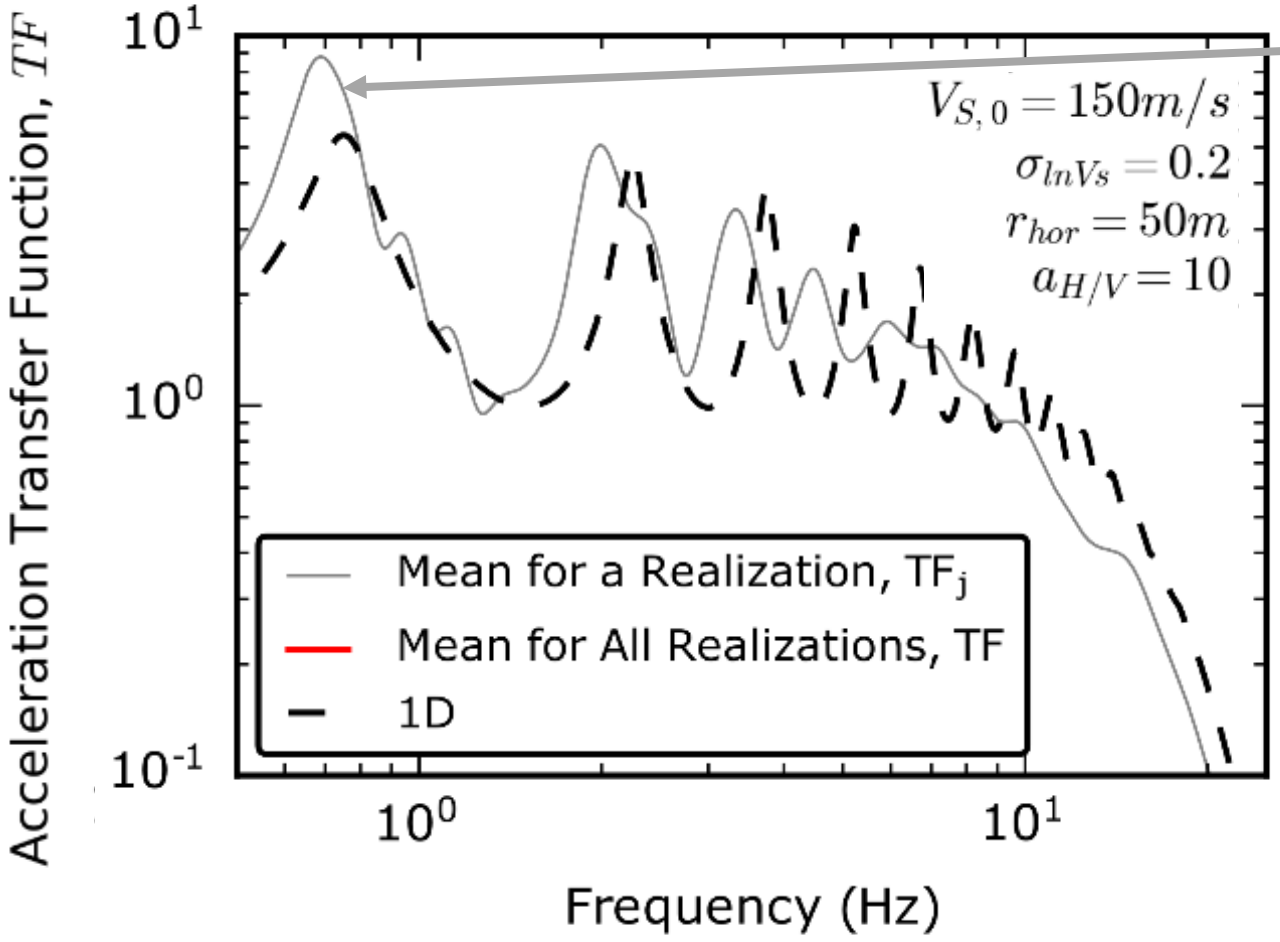
- $TF_{i,j}$ = TF at node i of realisation j
- TF_j = Average TF for realisation j
- TF = Average TF across all 10 realisations

Response at an Individual Node

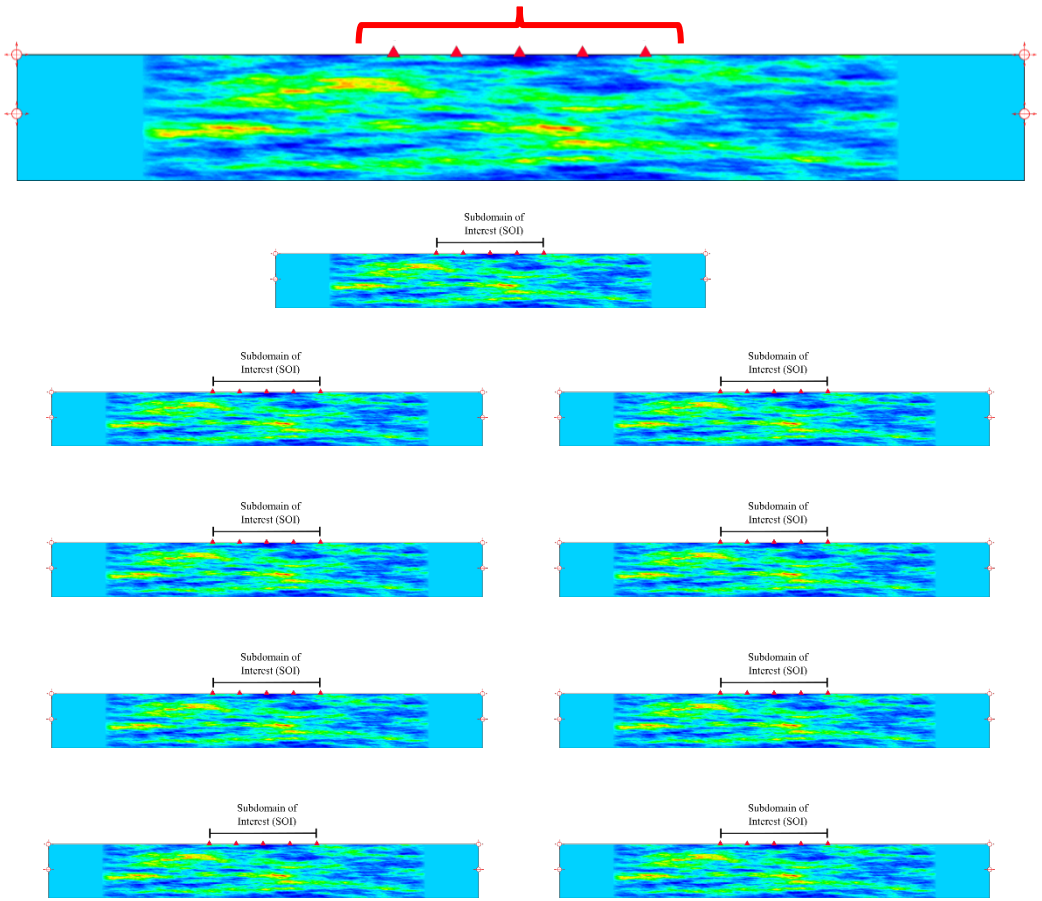


- Reduction in peak-to-trough ratio
  - Energy redistributed across wider *f* band
  - At each Node!!!
- Reduction in TF at high frequencies
  - HF more scattered by these length scales

Average Response for Each Realisation

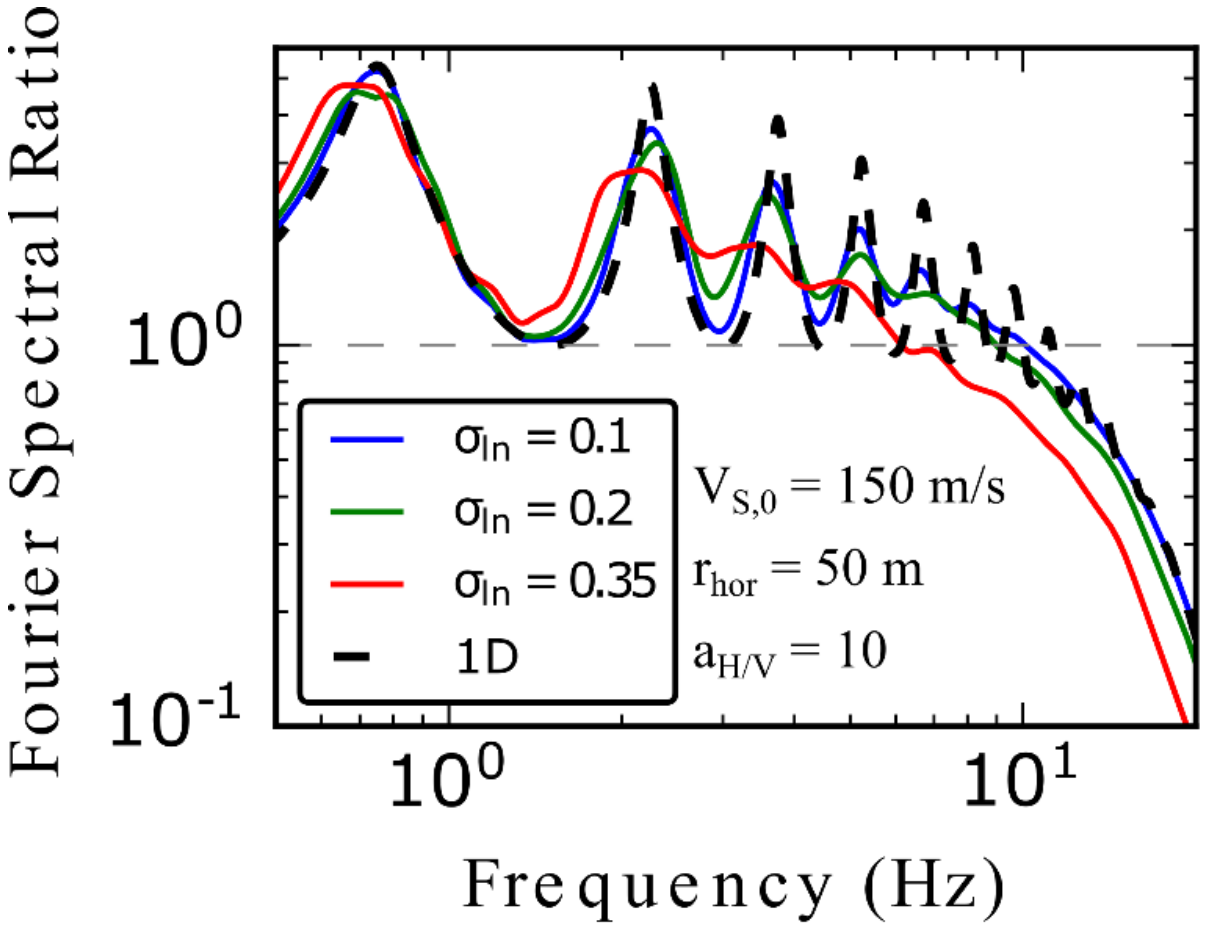


TF_j = mean(5 nodal $TF_{i,j}$ of Realisation j)



Average Response for Each Permutation

Effects of σ_{lnVs}



Increasing σ_{lnVs}:

- Greater reduction in peak-to-trough ratio
- Greater reduction of TF at high frequencies

$$HF_{ratio} = \frac{1}{N_f} \sum_{f=5\ Hz}^{20\ Hz} \frac{TF_{f,2D}}{TF_{f,1D}}$$

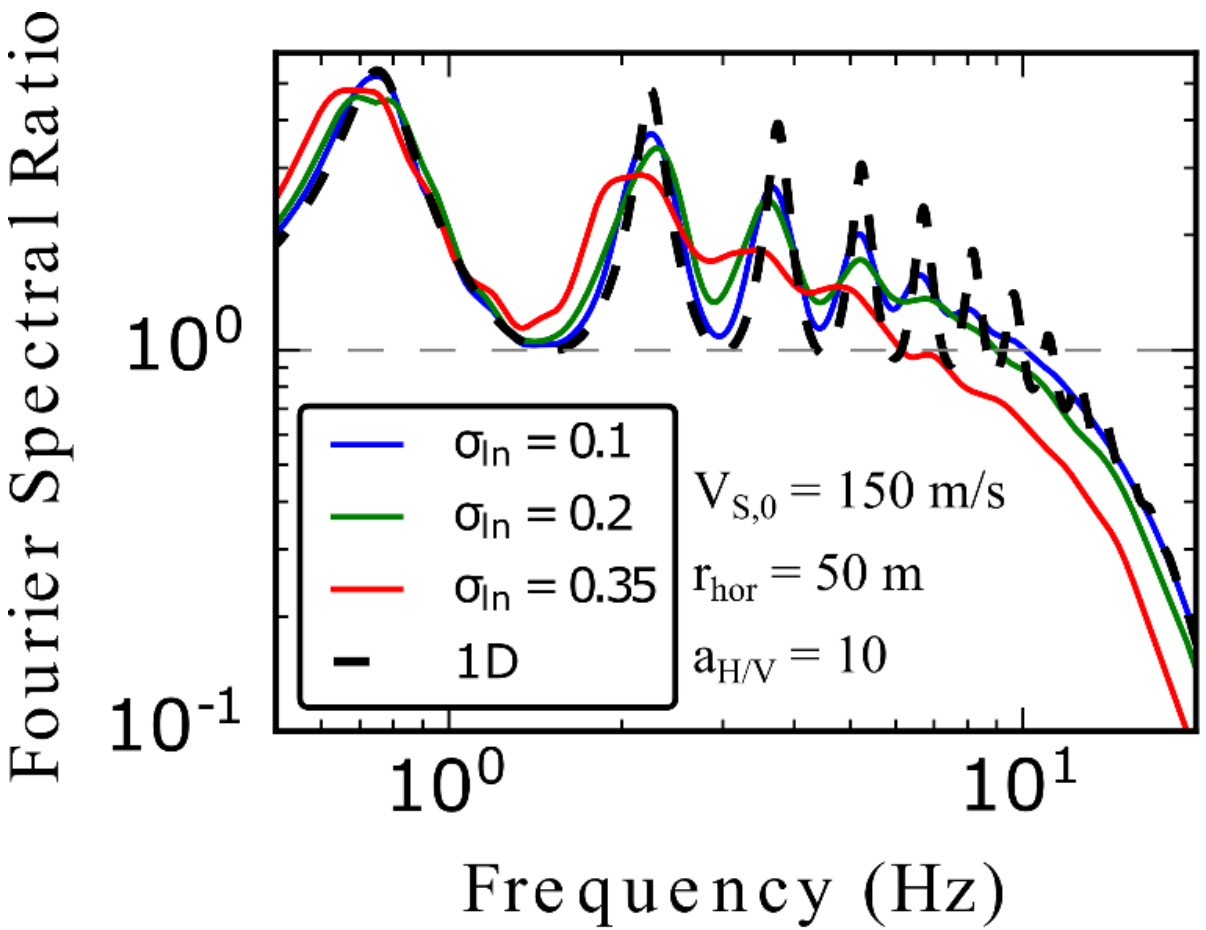
$$HF_{ratio} = 1.0, 0.9, 0.6$$ Nonlinear relationship with σ_{lnVs}

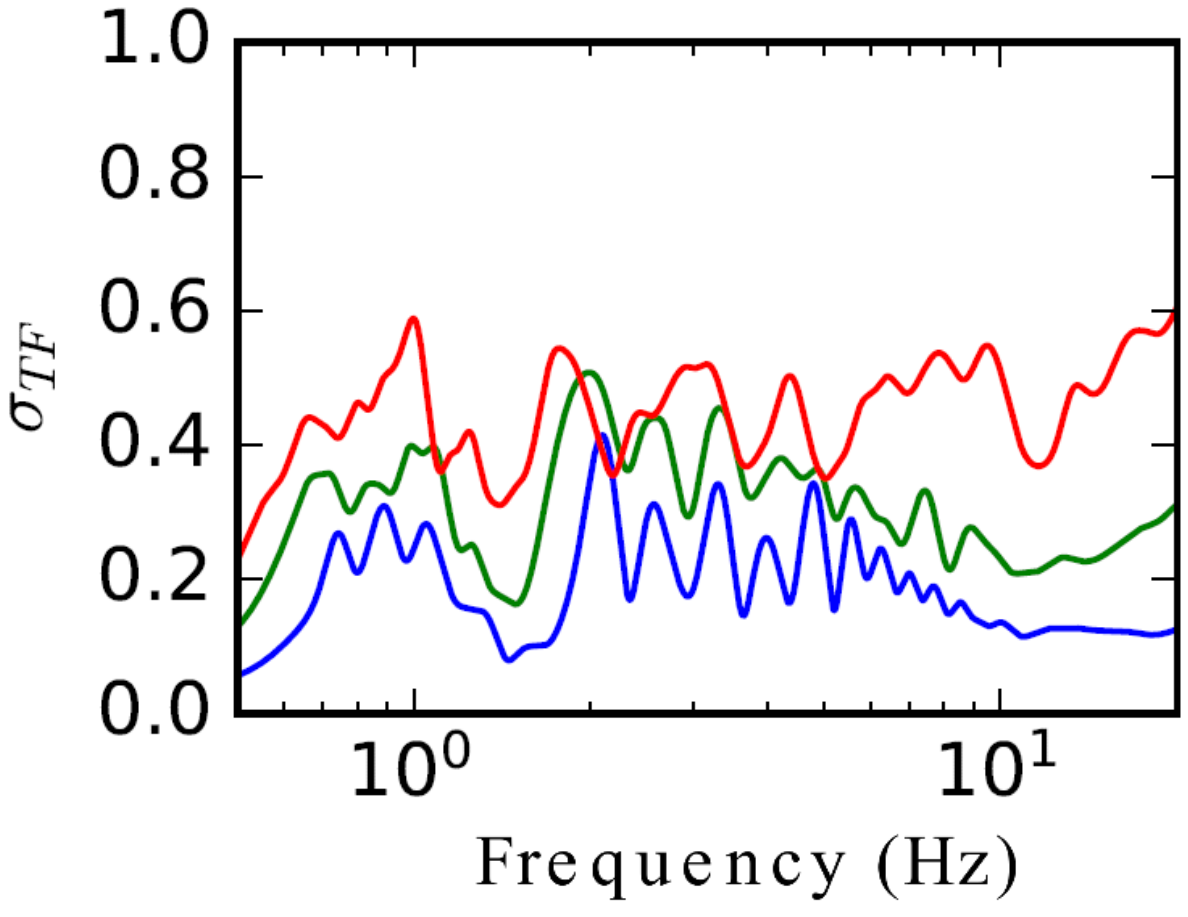
Two reasons:

- Higher variance → more wave scattering
- Node-to-node and realisation-to-realisation variability
  → More averaging or smoothing

Average Response for Each Permutation

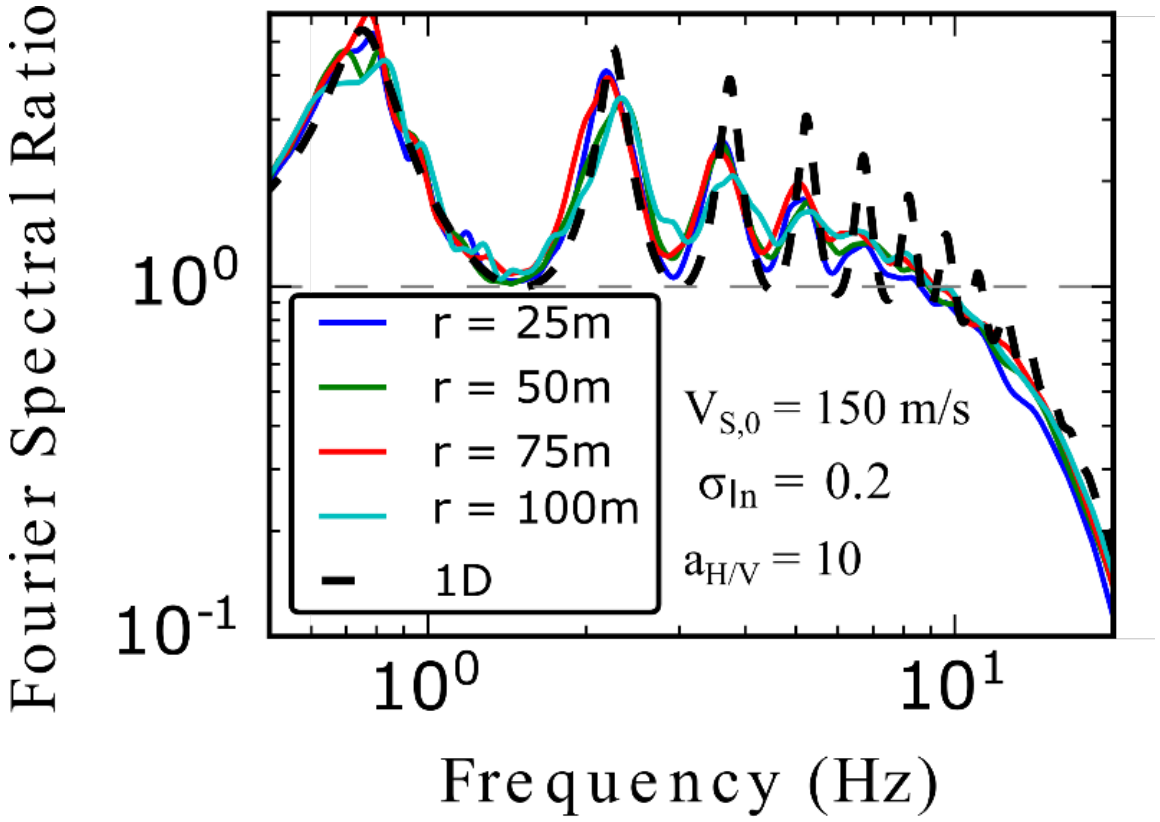
Effects of σ_{lnVs}





Average Response for Each Permutation

Effects of r_{hor}



- Little effect from varying r_{hor}
- More HF attenuation with smaller r_{hor}

$$HF_{ratio} = 0.8, 0.9, 0.9, 0.9$$

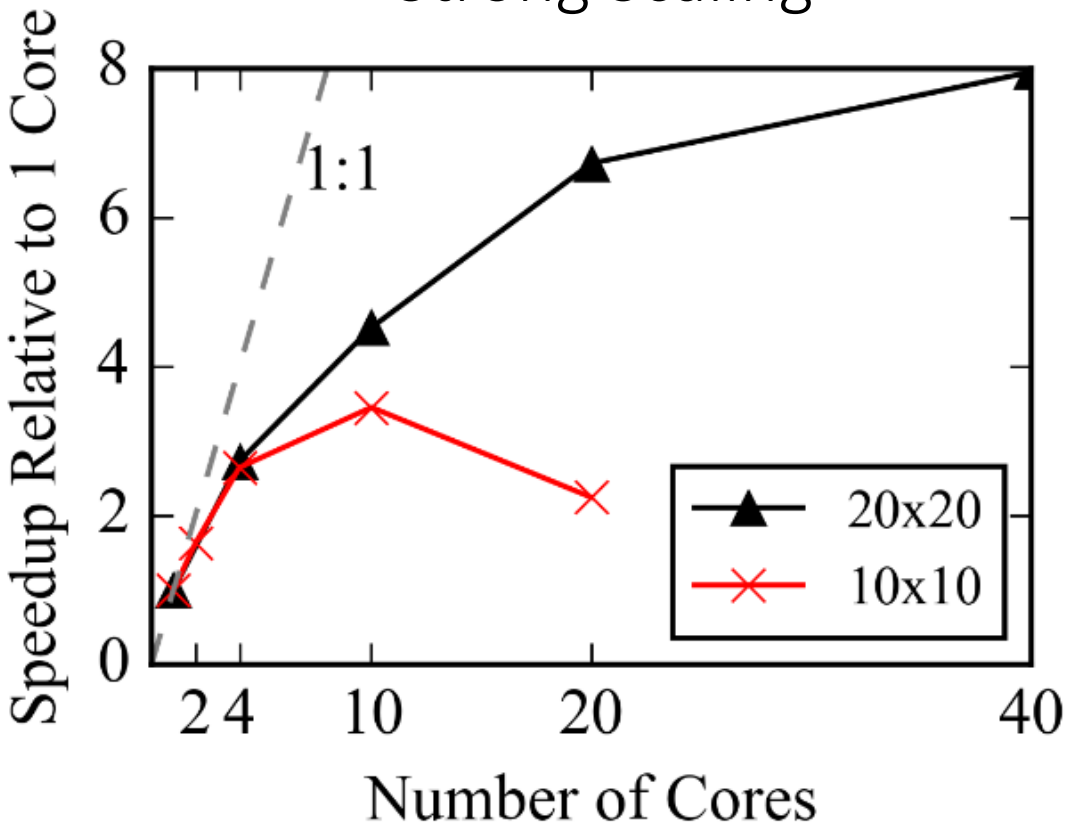
- 4x change in r_{hor}:
  - HF_{ratio}: 0.9 → 0.8
- 3.5x change in σ_{lnVs} :
  - HF_{ratio}: 1.0 → 0.6

OpenSees Scalability

50x50
17 hrs on 20 cores!

500x500 = 170,000 hrs??

Strong Scaling



Weak Scaling