Non-linear Soil Amplification for Horizontal GM

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Background

- Update to Walling et. al. 2008

- Simulation-based model to describe non-linearity in site response
  - RVT-based, 1D site response method (RASCALS)
  - Combines point-source stochastic for source with equivalent-linear for site response
  - 11 values of PGA - 0.01 through 1.5 g
  - Four models for describing soil properties (G/G_{max}, damping curves)
  - Reference velocity for amplification factors: V_{s30}=1170 m/s
  - 30 randomizations of profile depth, soil properties, etc.

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Motivation

- Simulation database expanded and updated
  - Includes M5, M6, M7
  - Includes Vs30 as low as 190 m/s

- Explore Sa(T) vs. PGA as shaking input parameter
  - Increase ease of application for hazard analyst
  - Other studies have shown Sa(T) works well (e.g. Bazzurro&Cornell 2004, Chiou and Youngs 2008)

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Range of simulation results used for model development

V_{s30} (m/sec)	***Depth to top of rock (V_{s30}=1 Km/sec)***	***Material Model used for nonlinear properties***
190	9-305 m	PR
270	9-305 m	PR, EPRI
400	9-305 m	PR, EPRI
560	9-305 m	PR, EPRI
760	79 m	PR, EPRI
900	79 m	PR

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Functional form

$$\ln(Amp) = f_L(V_{s30}) + \ f_{NL}\ (GM_{Rock}, V_{s30})$$

$$\ln(Amp) = \begin{cases} a\ ln\left(\frac{V^*_{S30}}{V_{Lin}}\right) - b\ ln(PGA_{Rock} + c) & \\ +\ b\ ln\left(PGA_{Rock} + c\left(\frac{V^*_{S30}}{V_{Lin}}\right)^n\right) + d & for \quad V_{s30} < V_{Lin} \\ (a + bn) ln\left(\frac{V^*_{S30}}{V_{Lin}}\right) + d & for \quad V_{s30} \geq V_{Lin} \end{cases}$$

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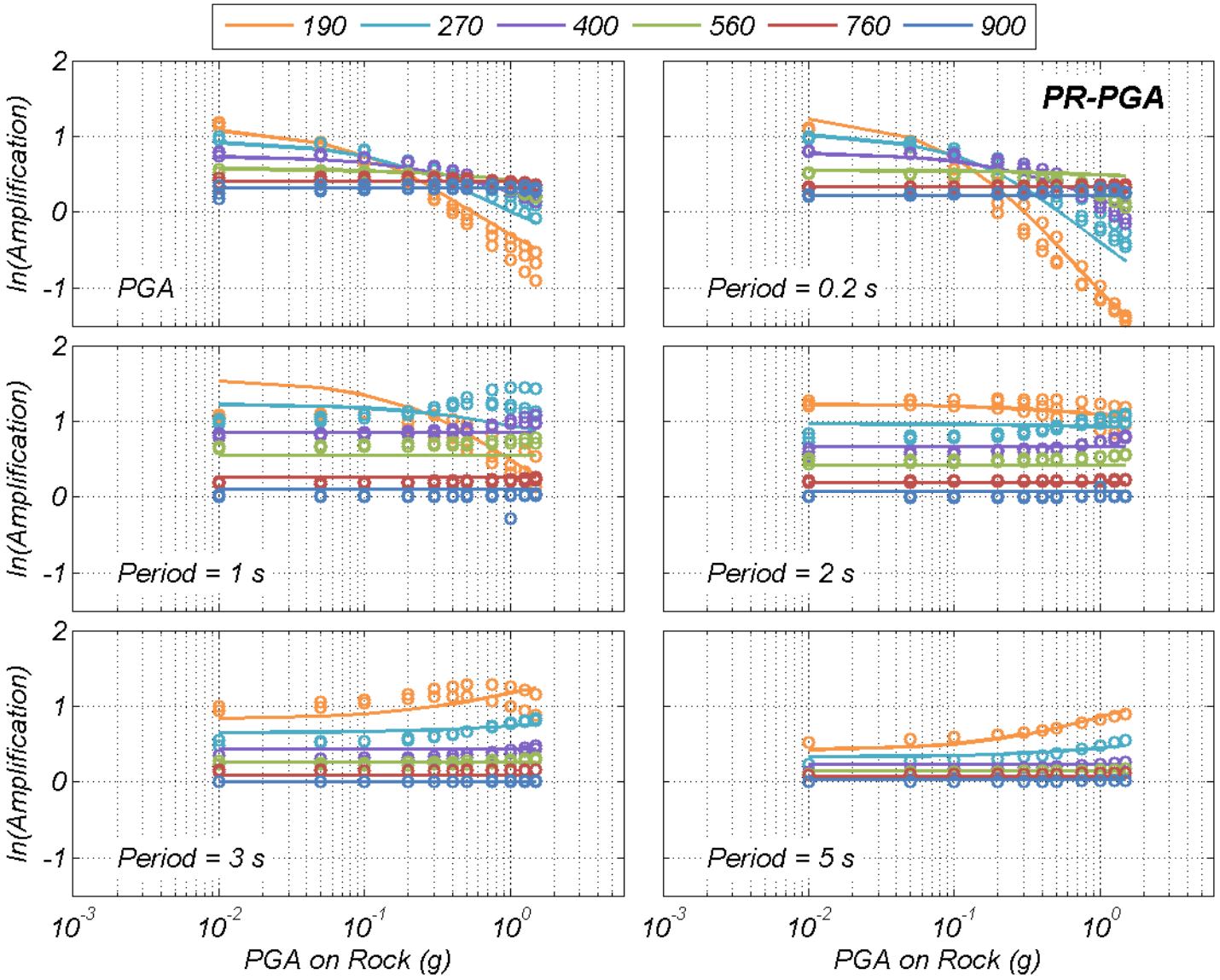
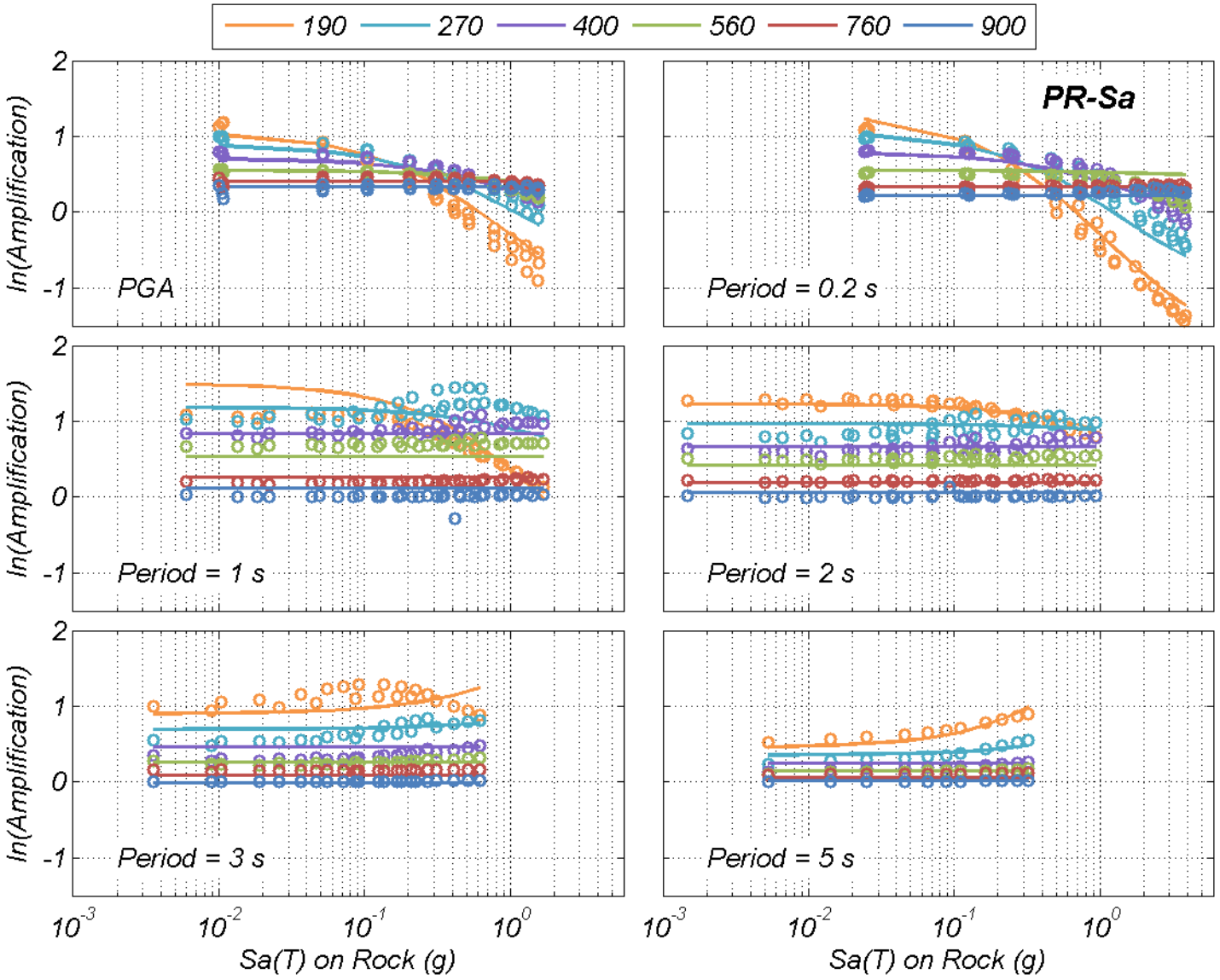

190
270
400
560
760
900
PR-PGA
ln(Amplification)
PGA
Period = 0.2 s
Period = 1 s
Period = 2 s
Period = 3 s
Period = 5 s
2
1
0
-1
10^{-3}
10^{-2}
10^{-1}
10^{0}
PGA on Rock (g)


190
270
400
560
760
900
PR-Sa
PGA
Period = 0.2 s
Period = 1 s
Period = 2 s
Period = 3 s
Period = 5 s
ln(Amplification)
Sa(T) on Rock (g)
2
1
0
-1
10^{-3}
10^{-2}
10^{-1}
10^{0}

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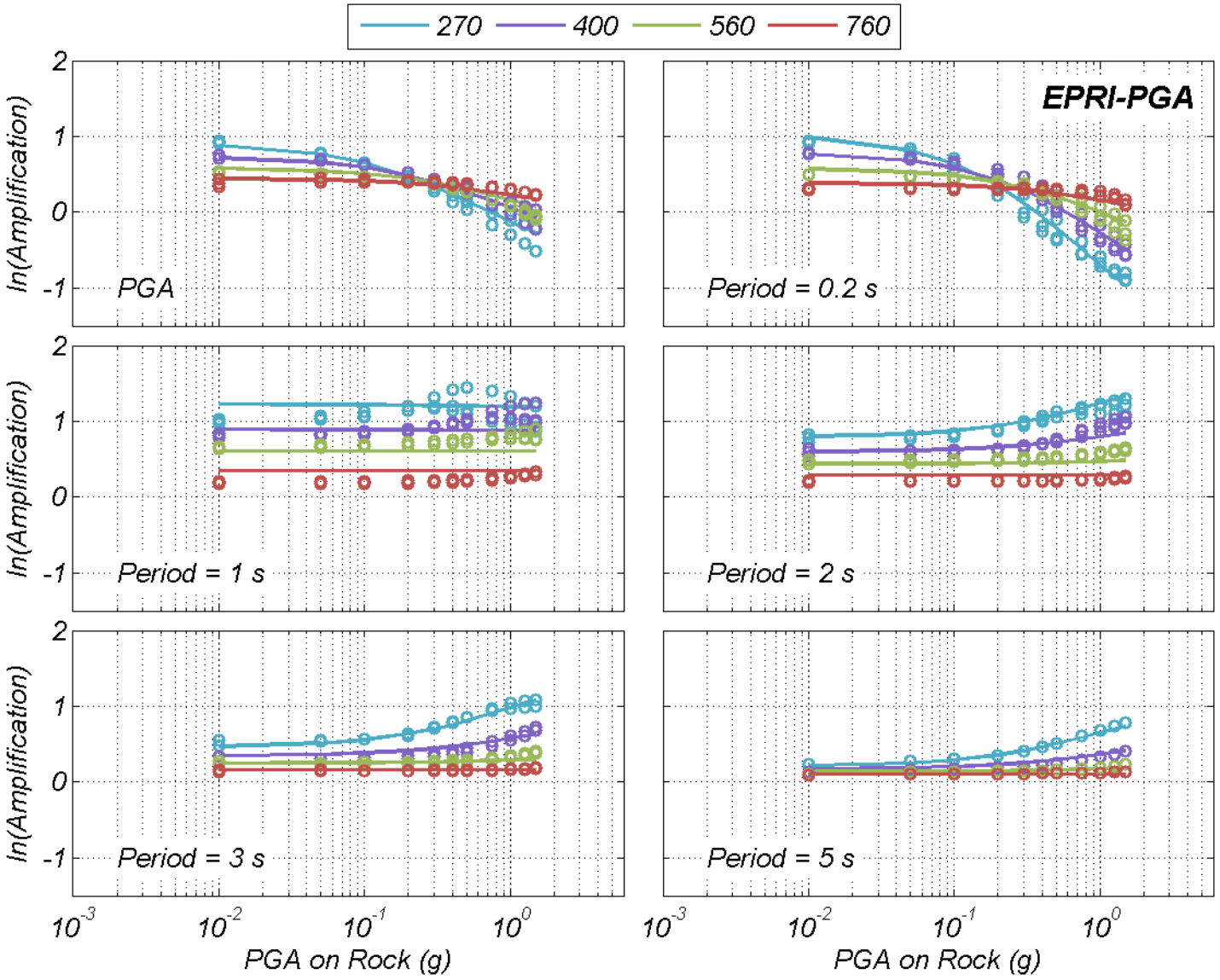
270
400
560
760
EPRI-PGA
ln(Amplification)
PGA
Period = 0.2 s
Period = 1 s
Period = 2 s
Period = 3 s
Period = 5 s
2
1
0
-1
10^{-3}
10^{-2}
10^{-1}
10^{0}
PGA on Rock (g)

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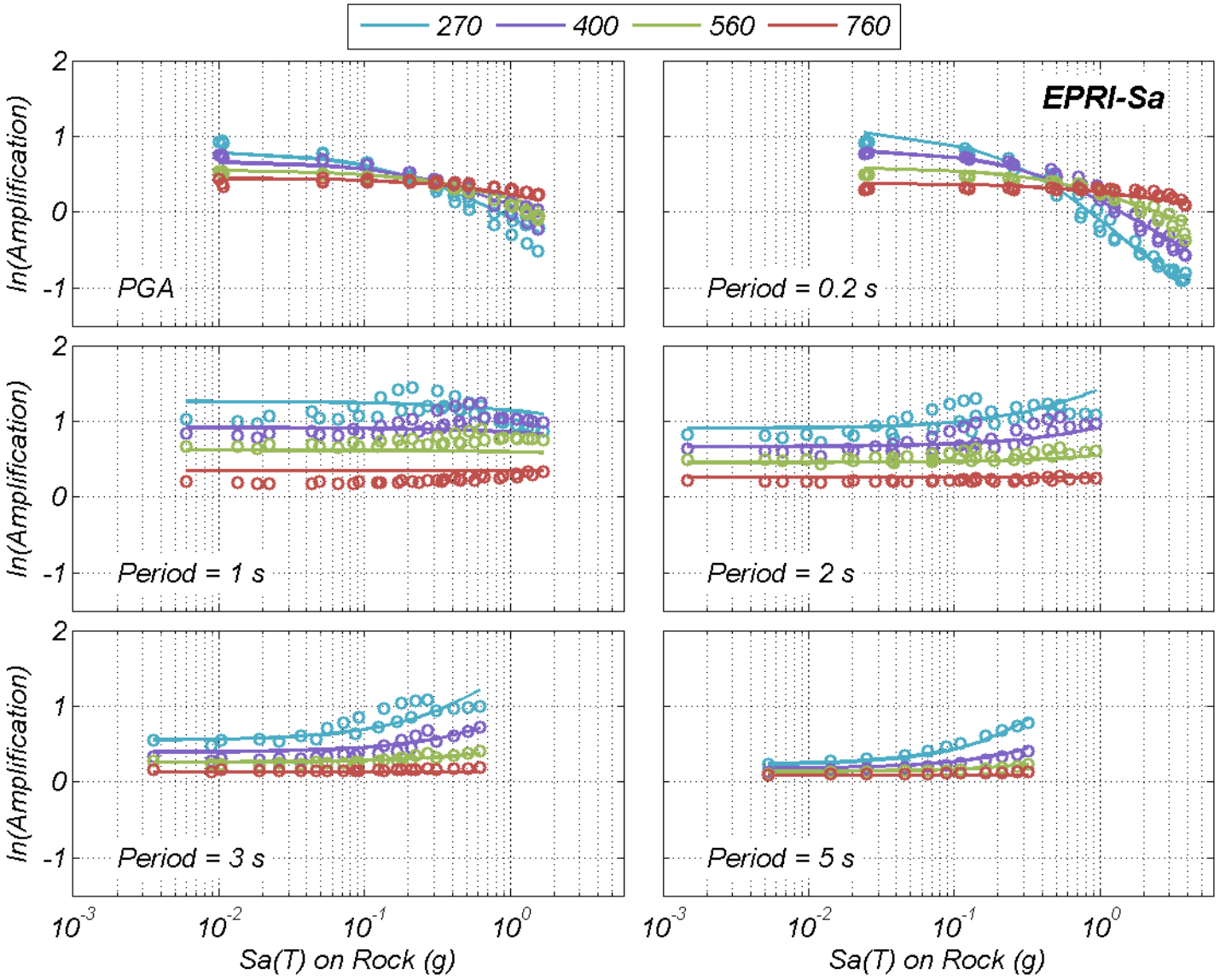
270
400
560
760
EPRI-Sa
ln(Amplification)
PGA
Period = 0.2 s
Period = 1 s
Period = 2 s
Period = 3 s
Period = 5 s
Sa(T) on Rock (g)
Sa(T) on Rock (g)

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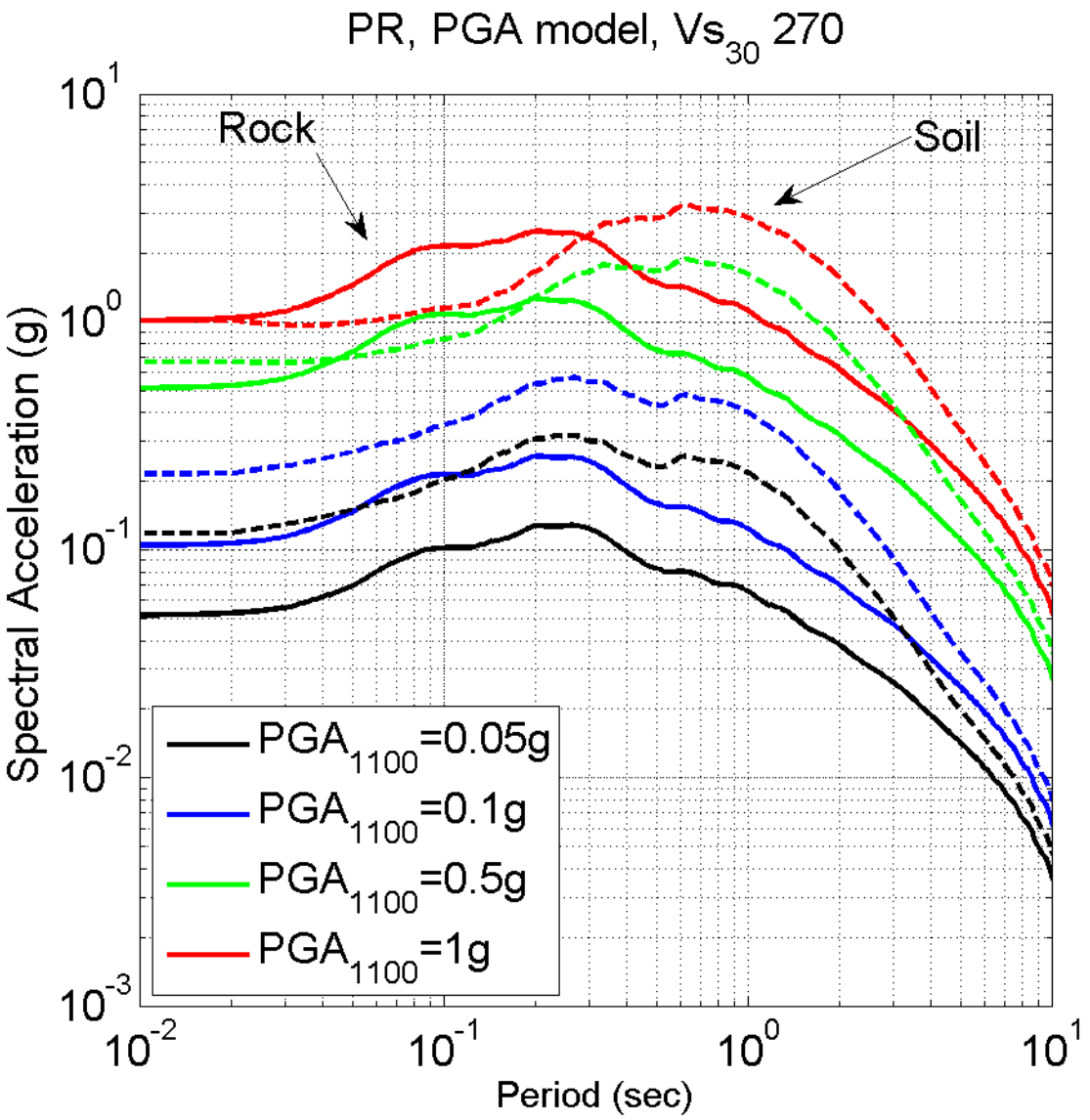
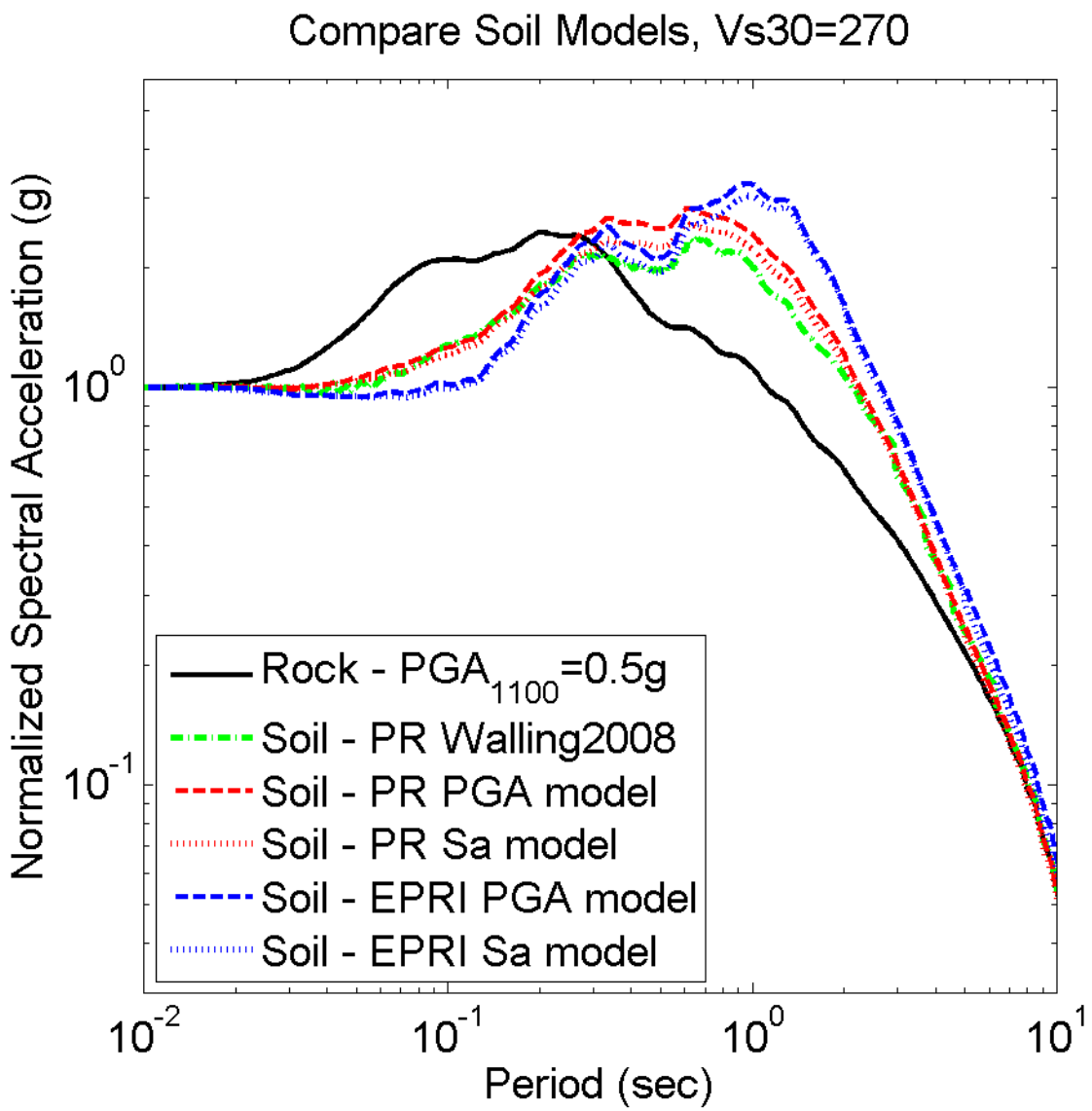

PR, PGA model, Vs30 270
Rock
Soil
Spectral Acceleration (g)
Period (sec)
PGA1100=0.05g
PGA1100=0.1g
PGA1100=0.5g
PGA1100=1g


Compare Soil Models, Vs30=270
Normalized Spectral Acceleration (g)
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
Period (sec)
Rock - PGA_{1100}=0.5g
Soil - PR Walling2008
Soil - PR PGA model
Soil - PR Sa model
Soil - EPRI PGA model
Soil - EPRI Sa model

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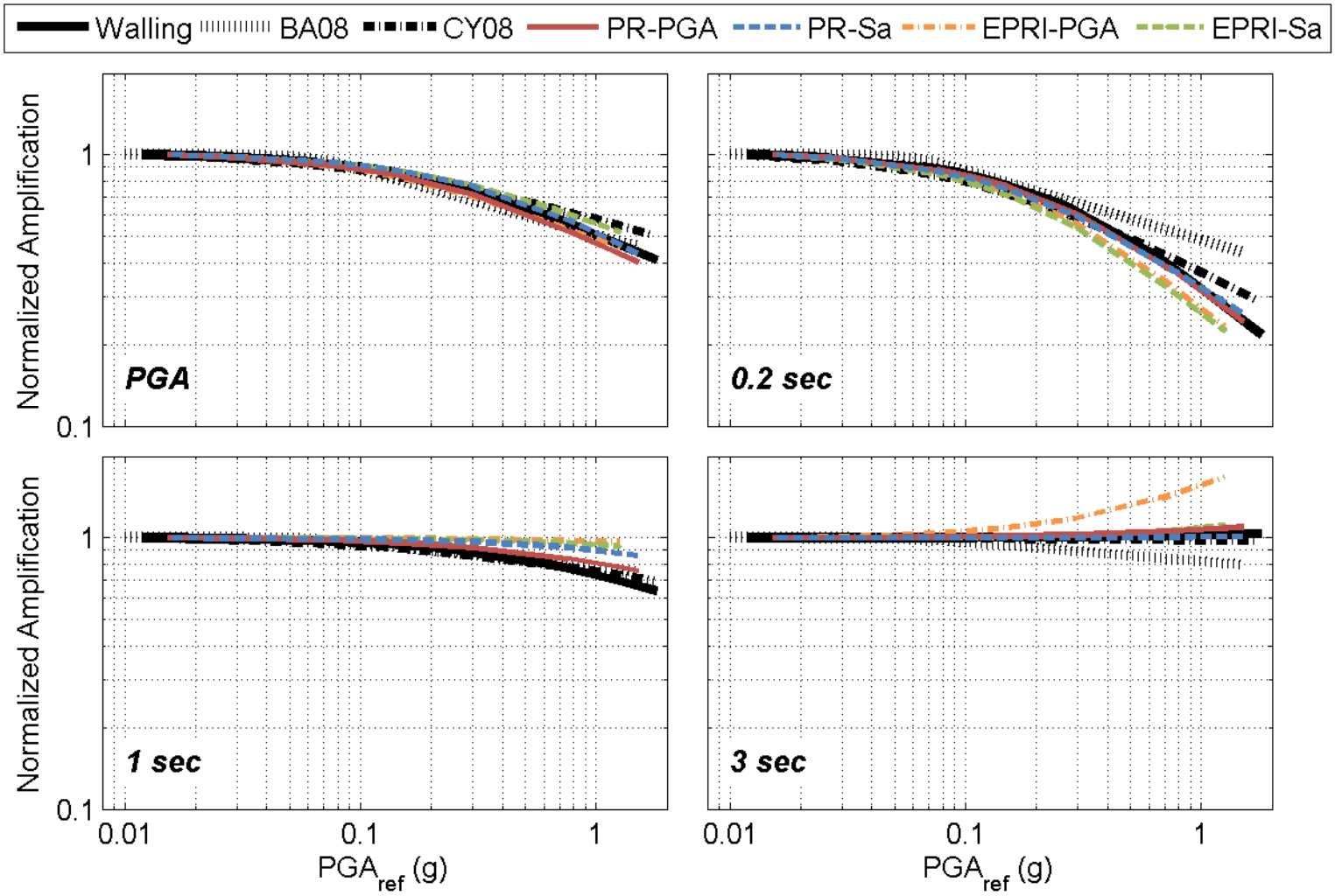
Nonlinear Soil Amplification for Vs_{30}=270, with respect to $Vs_{30,ref}$=760 m/s



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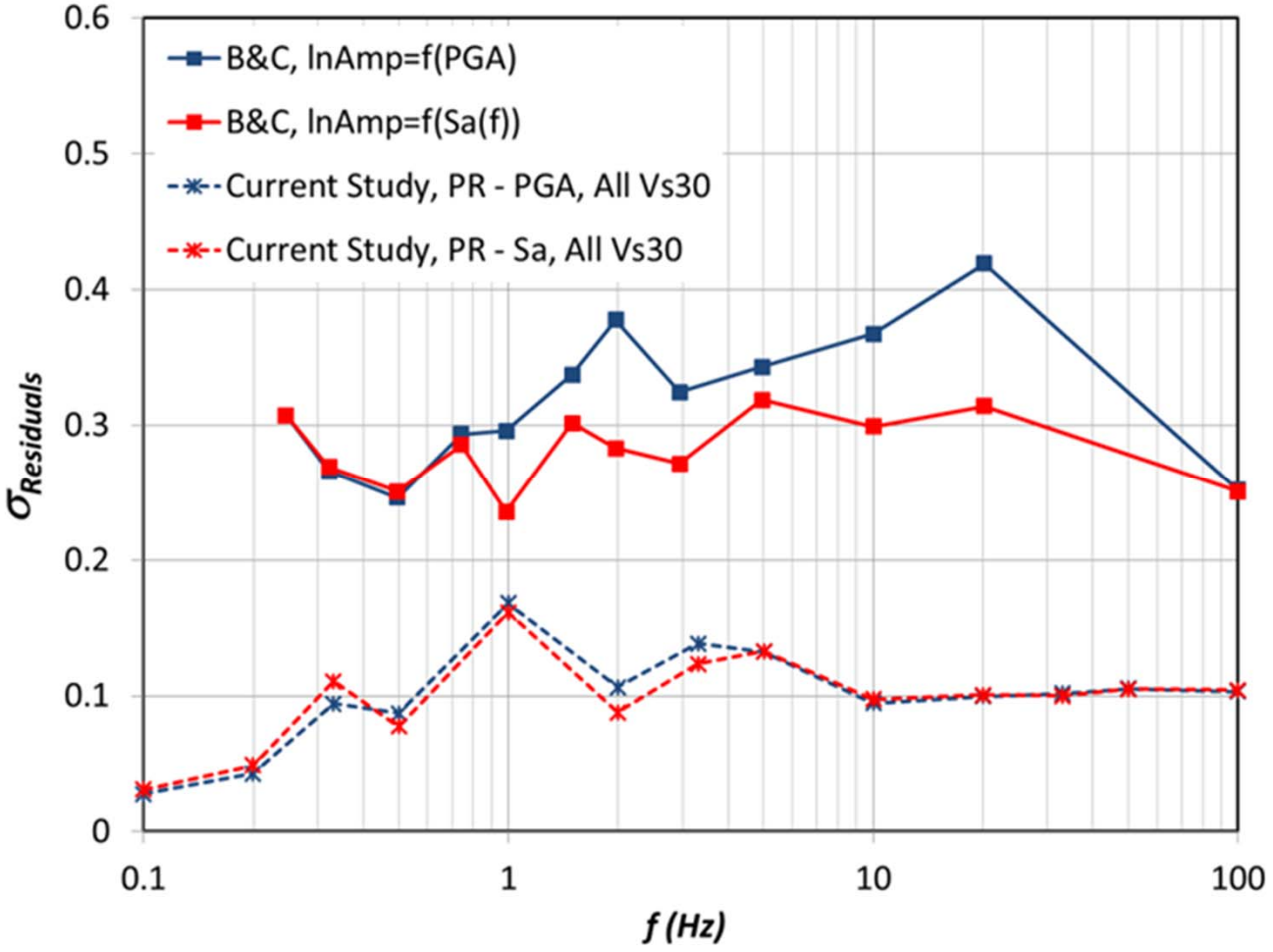
Should I use PGA or $S_a(T)$ as input motion?



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$$b, \ln(V_{Lin}) = \begin{cases} \beta_2 & T \geq T_2 \\ \propto_0 + \sum_{i=1}^{8} \propto_i [ln(T/T_0)]^i & T_1 < T < T_2 \\ \beta_1 & T \leq T_1 \end{cases}$$

	PR PGA Model		PR Sa Model		EPRI PGA Model		EPRI Sa Model	
	V_{LIN}	b	V_{LIN}	b	V_{LIN}	b	V_{LIN}	b
T_0	0.02	0.04	0.02	0.06	0.02	0.04	0.013	0.03
T_1	0.02	0.06	0.02	0.082	0.02	0.04	0.013	0.03
T_2	0.6	8.8	0.8	5.65	1.1	8.8	0.45	5.5
α_0	6.514	-1.170	6.554	-1.300	7.093	-0.778	7.291	-0.710
α_1	0.476	-0.018	0.348	0.517	0.064	-0.230	-0.038	-0.014
α_2	-0.558	0.126	0.100	-2.469	1.674	1.224	0.163	-0.431
α_3	0.887	0.042	-0.165	3.450	-2.025	-2.722	0.925	0.982
α_4	-0.662	-0.743	-0.023	-2.800	0.860	1.845	-1.308	-1.432
α_5	0.188	0.447	0.024	1.042	-0.159	-0.533	0.624	0.878
α_6	-0.018	-0.090	-0.003	-0.167	0.011	0.070	-0.130	-0.252
α_7	0	0.006	0	0.009	0	-0.004	0.010	0.034
α_8	0	0	0	0	0	0	0	-0.002
β_1	6.514	-1.170	6.554	-1.30	7.093	-0.778	7.291	-0.710
β_2	315.5	0.394	312.0	4.48	610.0	0.411	738.0	2.470
n	1.5		1.5		1.5		1.5	
c	1.4		2.4		2.0		3.7	

Summary

- Four models are presented:
  - PR-PGA
  - PR-Sa
  - EPRI-PGA
  - EPRI-Sa
- Sa(T)-based models generally preferred for ease of applicability, although both forms are statistically equivalent
- Nonlinearity generally consistent with Walling2008 and with CY2008

Thank You

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